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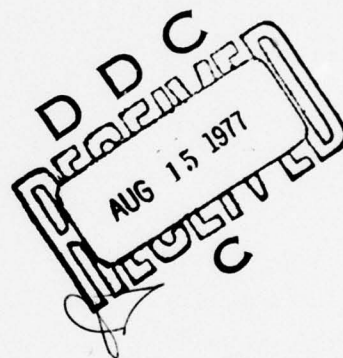
VOLUME 11 OF 11

SPILL RISK ANALYSIS PROGRAM:
METHODOLOGY DEVELOPMENT AND DEMONSTRATION
POLLUTION INCIDENT REPORTING SYSTEM
FINAL REPORT

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APRIL 1977



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16. Abstract <p>This report describes research and results in the development and demonstration of systematic methods of assessing the effectiveness of either proposed or recently implemented merchant marine safety regulations. The methods have been designed primarily to assist Coast Guard regulatory decision-makers in their selection of alternative means of reducing marine transportation casualties and spills of hazardous or polluting materials. The methodology involves both analytical and logical modeling of ship collisions is primarily in terms of the physical parameters (e.g., vessel size, speed, maneuverability) of the system, but human response parameters are also considered. Logical modeling of casualties addresses the effects of changes in regulations and involves structured conduct of quasi-experiments using the Coast Guard data base of marine casualty reports. A preliminary analysis of the Coast Guard Pollution Incident Reporting System (PIRS) is also included (Volume II). This report supplements, but does not replace information contained in Report No. CG-D-15-75, Spill Risk Analysis Program Phase II Methodology Development and Demonstration (NTIS AD-785026).</p>			
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yd	yards	0.9	meters	m	meters	3.3	feet
mi	miles	1.6	kilometers	km	kilometers	1.1	yards
						0.6	miles
AREA				AREA			
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fl oz	fluid ounces	30	milliliters	l	liters	1.06	quarts
c	cups	0.24	liters	l	liters	0.26	gallons
pt	pints	0.47	liters	m ³	cubic meters	35	cubic feet
qt	quarts	0.95	liters	m ³	cubic meters	1.3	cubic yards
gal	gallons	3.8	liters				
ft ³	cubic feet	0.03	cubic meters				
yd ³	cubic yards	0.76	cubic meters				
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*1 in = 2.54 (exact). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price \$2.25, SD Catalog No. C13.10.286.

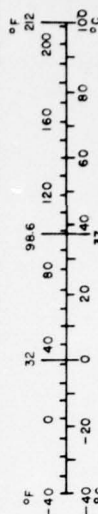


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I. INTRODUCTION

Early efforts in the Spill Risk Analysis project indicated that a detailed examination of both the number and type of spill incidents and the volume of effluent generated by these incidents would provide the Coast Guard with important information. This assessment was based on information gained from the Pollution Incident Reporting System (PIRS) data base maintained at U.S. Coast Guard headquarters. This first look showed that only 29 percent of the spill incidents reported originated from casualties (15 percent of spill volume). Incidents at marine transfer facilities accounted for 18 percent of the total (14 percent spill volume). Incidents reported from other shore and offshore facilities generated the remaining 53 percent and 71 percent of the volume. With both a majority of spill incidents and spillage volume originating from facilities rather than vessels, a thorough investigation of this sector of the spill-risk problem was obviously justified. Beside a simple general knowledge of the facilities problem, a secondary goal would be to assess the ability of the general risk analysis techniques which had already been developed for vessel casualties in this new area.

At the very start of this project, the importance of the PIRS data base was apparent. The PIRS is not simply the only centralized source of spill statistics available, but it also, to a very great extent, determines the level of detail required in reports from field activities. Therefore, the study that is now being reported was begun with a detailed analysis of the structure of the PIRS. The problem of integrating PIRS data over the full period of its life was somewhat complicated by the fact that the PIRS reporting format had been revised in 1973. The way in which this problem was solved, the details of other modifications to the basic PIRS data which were made for the purposes of this study, are addressed in Section II.

The sources and causes of pollution incidents have a very great effect upon the type of regulatory initiatives which might be practical for the U.S. Coast Guard. This area is complicated by the fact that many of the incidents reported under the PIRS are not within Coast Guard jurisdiction. This aspect of the study is considered in Section III.

The volume of an average spill from a given source/cause combination and the variation in this volume is another important matter which relates to the potential effectiveness of Coast Guard regulatory efforts and the most productive areas where these efforts may be applied. The breakdown and scaling of this information is done in Section IV.

When dealing with U.S. Coast Guard preventable incidents, it was soon noted that vessel casualties began to assume a more important role. Vessel casualties are extracted from the general population of pollution incidents and examined in detail in Section V. The purpose of this analysis was to determine the kinds of vessels that figure most prominently in pollution discharges, the type of accidents in which they are most often involved, and the severity of the pollution that may be expected to result.

The pollution volume produced by transportation-related facilities (i.e., under DOT jurisdiction), while less than that produced by vessels is not a trivial amount. The similarities and differences of the two problem areas are addressed in Section VI. The purpose of this analysis is to determine the most promising methodological approach to developing effective policies for curtailing the number of facility pollution incidents.

II. THE DATA BASE

THE POLLUTION INCIDENT REPORTING SYSTEM (PIRS)

All of the distributions presented in this report have been derived from analysis of data gathered and processed through the PIRS, established in 1970 by the Coast Guard's Office of Marine Environment and Systems. Through December of 1973 (the latest date for which data are currently available), this system had amassed a wealth of information concerning many facets of the circumstances surrounding 40,808 incidents involving the discharge of an estimated total of 90 million gallons of pollutants into U.S. waterways. ^{1/} In 1973, the reporting format used by PIRS was revised and expanded to provide more detailed information on certain particulars. For the analysis here, which focuses on the source, size and cause of pollution incidents during the 1971 through 1973 period, this revision effected primarily the classification by cause. The measures taken to make the 1973 "source" and "cause" data compatible with that collected in 1971 and 1972 are shown in Figures 1 and 2.

The question quite naturally arises as to how the Coast Guard becomes informed that a pollution incident has occurred in order that it may investigate the event and record the circumstances. Examination of this distribution shows that the offending entity (i.e., the person or organization responsible for the pollution incident) itself reported the incident in over one-half (53 percent) of those cases where information on this point was recorded. About one-fifth

^{1/} The 8,736 incidents recorded during 1970 are not addressed on the ground that the data are apt to be both less reliable (an adjustment period would be expected to be required for the newly introduced system) and less relevant than those collected in subsequent years.

PIRS SOURCE CATEGORY, 1971 & 1972 DATA

PIRS SOURCE CATEGORY, 1973 DATA

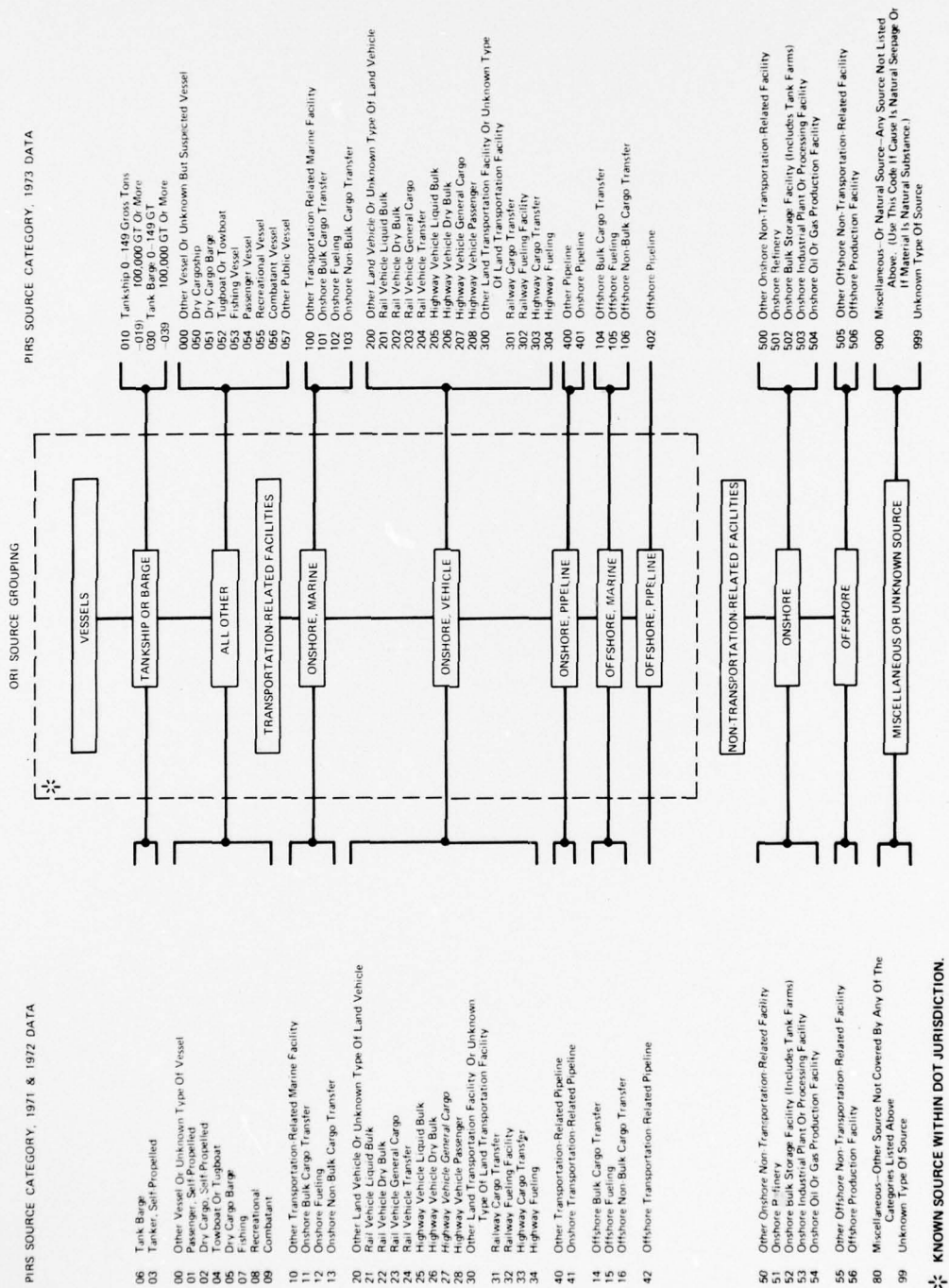


FIGURE 1. COMPARISON OF ORI SOURCE GROUPING WITH PIRS SOURCE CATEGORIES

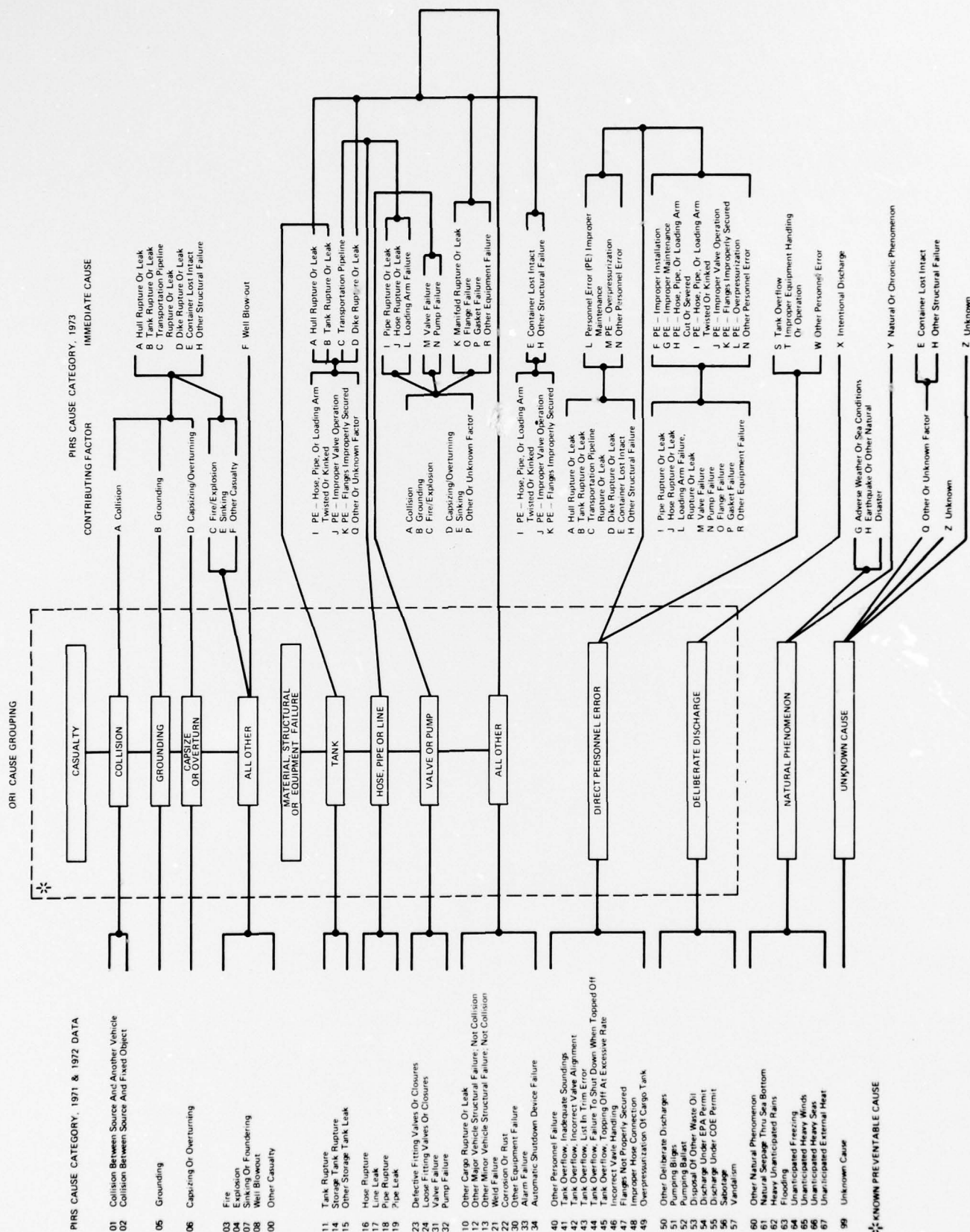


FIGURE 2. COMPARISON OF ORI CAUSE GROUPING WITH PIRS CAUSE CATEGORIES

(19 percent) of the incidents were detected by Coast Guard surveillance patrols or inspections. The same fraction (19 percent) was reported by commercial entities or private parties other than those responsible for the spill. The remaining nine percent were reported by other government agencies.

The "notifier" distribution is discussed further in Section III, From Pollution Event to Pollution Incident. It is apparent from the above statistics, however, that the Pollution Incident Reporting System is reliant in very large measure upon the cooperation of the offending party for its information. How this fact may influence the data collected in PIRS might be considered a subject for further research. On the one hand, the offender is required by law to report a pollution incident and may be penalized for his failure to do so. On the other hand, he may also be penalized for the offense itself should it be reported. These facts could distort the data in a number of ways. The offender's perception of the probability that the incident would be detected by someone else (greater, one would expect, for larger spills or those involving a spectacular cause such as collision or explosion) could be one distorting influence. The severity of the consequences for him if he reports the incident (less, one would expect, for smaller spills or those with more readily rationalized causes such as a natural phenomenon—as opposed, for example, to personnel negligence) might be another.

CLASSIFICATION OF THE PIRS DATA BY SOURCE AND CAUSE

The PIRS format in use during 1971 and 1972 stipulated 41 possible specific sources and 54 possible specific causes of pollution incidents. In the revised 1973 format, sources and causes were expanded to 60 and 270 respectively (see Appendix A).

Sources responsible for pollution incidents have been organized in three general groups: vessels, transportation-related facilities, and non-transportation-related facilities. The guidelines in use to distinguish non-transportation-related facilities (regulated by the Environmental Protection Agency (EPA)) from facilities related to transportation (regulated by the Department of Transportation (DOT)) are summarized in Appendix B. The distinction is an important one since the Coast Guard bears responsibility for remedial action in the event of a water pollution incident regardless of the source; but has regulatory jurisdiction, and hence the ability to effect preventive measures, only over vessels and marine transport facilities. From the point of view of Coast Guard management, this means that nearly 51 percent^{2/} of the clean-up burden on its operating resources is uncontrollable: the 509 gallons out of each 1,000 gallons spilled that originate from a non-transportation-related facility, a vehicle, or a pipeline.

^{2/} Assuming overall clean-up burden to be proportionate to the aggregate volume spilled.

Similarly, explicit causes have been arranged within five general groups: casualty; material, equipment, or structural failure; direct personnel error; deliberate discharge; and natural phenomenon. The first two groupings, those of greatest interest, have been subdivided as indicated in Figure 2. It should be noted that the "collision" component of the "casualty" group includes collisions with fixed objects ("rammings") as well as between moving vessels.^{3/}

The "direct personnel error" group also deserves comment. The key to this classification is the word "direct." It should not be interpreted as reflecting the full importance of the role of personnel error as a cause of pollution. Human mistakes are frequently contributing factors in accidents, and therefore partially submerged within the casualty data. In fact, a major portion of the incidents attributed to material, equipment or structural failures might also be traced ultimately to human errors in maintenance or design. The recognition of this kind of causal interrelationship in the revised 1973 PIRS reporting format represents a major improvement over that in use previously. Detailed analysis of the 1973 data is required to achieve an appreciation of the full significance of personnel error in contributing to the pollution problem.

Just as the Coast Guard's span of control is narrowed by jurisdiction over the sources of pollution, so is it further reduced, at least in the short-run, by the practical limitations on controlling the effects of natural phenomena. Although it would be inaccurate to consider the pollution produced by this cause entirely uncontrollable, inasmuch as measures could be taken to make sources less vulnerable to such phenomena as storms and earthquakes, financial realities would place the benefits of such efforts far in the future. In other words, while design changes to protect against natural phenomena might be economically included in new construction projects, the costs of altering structures and facilities now in operation are generally not economically feasible. Meteorological prediction improvements might also be used to attack this cause. But again, major advances are not likely to appear in the near term. Consequently, cause as well as source has been considered in order to isolate that portion of the overall pollution problem of greatest relevance to Coast Guard management: the pollution arising from "preventable causes within USCG jurisdiction."

ALTERNATIVE STANDARDS FOR MEASURING THE POLLUTION PROBLEM

Another important management consideration in formulating an anti-pollution strategy is the question of which of the competing standards for grouping the problem is most significant—the number of incidents that occur or the volume of pollutants that is spilled. Since the data reveal a negative correlation between incidence and volume, with those source-cause combinations responsible for the largest shares of incidents accounting for only minor

^{3/} The format in use during 1971 and 1972 permitted distinction between collision with fixed and moving objects. The format in use in 1973 does not.

portions of the spillage while those which produce large volumes of spillage are reported far less frequently, a strategy aimed at achieving reductions in volume spilled would, therefore, concentrate on different sources and strive to prevent different kinds of events than one aimed at achieving reductions in the number of incidents taking place.

This dichotomy is demonstrated and further discussed in later sections. All in all, it would appear that volume spilled offers a better indication of the costs of pollution, both directly in Coast Guard remedial resources and indirectly in a broad socioeconomic context, than does incidence. It is by this standard that performance in controlling pollution is most apt to be judged.^{4/} The only costs better expressed as a function of the number of incidents reported are those incurred by the Coast Guard in administering the reporting system itself. If this appraisal is correct, the cost-effectiveness of continuing to investigate and record every pollution incident brought to Coast Guard attention merits reexamination. This issue is also addressed in subsequent sections.

In summary, it is recognized that there are many standards under which the effectiveness of a spill-risk program might be measured. The effects and costs, economic and social, of pollutant discharges are a function of size, location, frequency, chemical composition, and time of year at the very least. For purposes of this study, the choice of measures, based on information available from the PIRS, was essentially limited to volume or number of incidents. Volume was chosen for the reasons cited above. Definition of a more adequate measure of effectiveness is needed, but such an effort is beyond the scope of this study.

^{4/} There exists some controversy among ecologists as to whether the adverse environmental consequences of a given volume of pollution is related to the size of spills. And, if so, in which direction. In other words, is the total environmental impact of, say, one million gallons of spillage more severe if it is discharged in a single large spill, one hundred medium sized spills, or one thousand small spills? In the analysis that follows, it is assumed that equal volumes of spillage have equal environmental consequences.

III. SOURCES AND CAUSES OF POLLUTION

In this section, the distribution of pollution volume is examined in terms of the 15 combinations of three general sources (vessels, transportation-related facilities, and non-transportation-related facilities) and five general causes (casualty; material, equipment or structural failure; direct personnel error; deliberate discharge; and natural phenomenon) *described in the preceding section*. In subsequent sections, the most significant of these combinations are analyzed in greater detail.

THE DISTRIBUTION OF OVERALL VOLUME

In 1971, 1972, and 1973, the PIRS recorded a total of 32,072 incidents wherein pollutants were discharged into U.S. waterways. In 22,688 (71 percent) of these incidents, an estimate was made of the amount that was spilled—a total equivalent to 53,690,000 gallons over the three year period.^{1/} The bar chart in Figure 3 depicts the way in which this volume was distributed among the general source groups, and among the general cause groups within each source. As the figure illustrates, in the case of 7,420,000 gallons the source was either undetermined or did not fit any of the three major source groups in the classification system. In the case of another 2,230,000 gallons, the source was identified and categorized, but the cause was not.

^{1/} In some incidents, the estimate of quantity spilled was expressed in pounds. These estimates were converted to gallon equivalents at the rate of eight pounds to the gallon in order to establish a common denominator for analytical purposes. This conversion yielded about 1.8 million gallon equivalents.

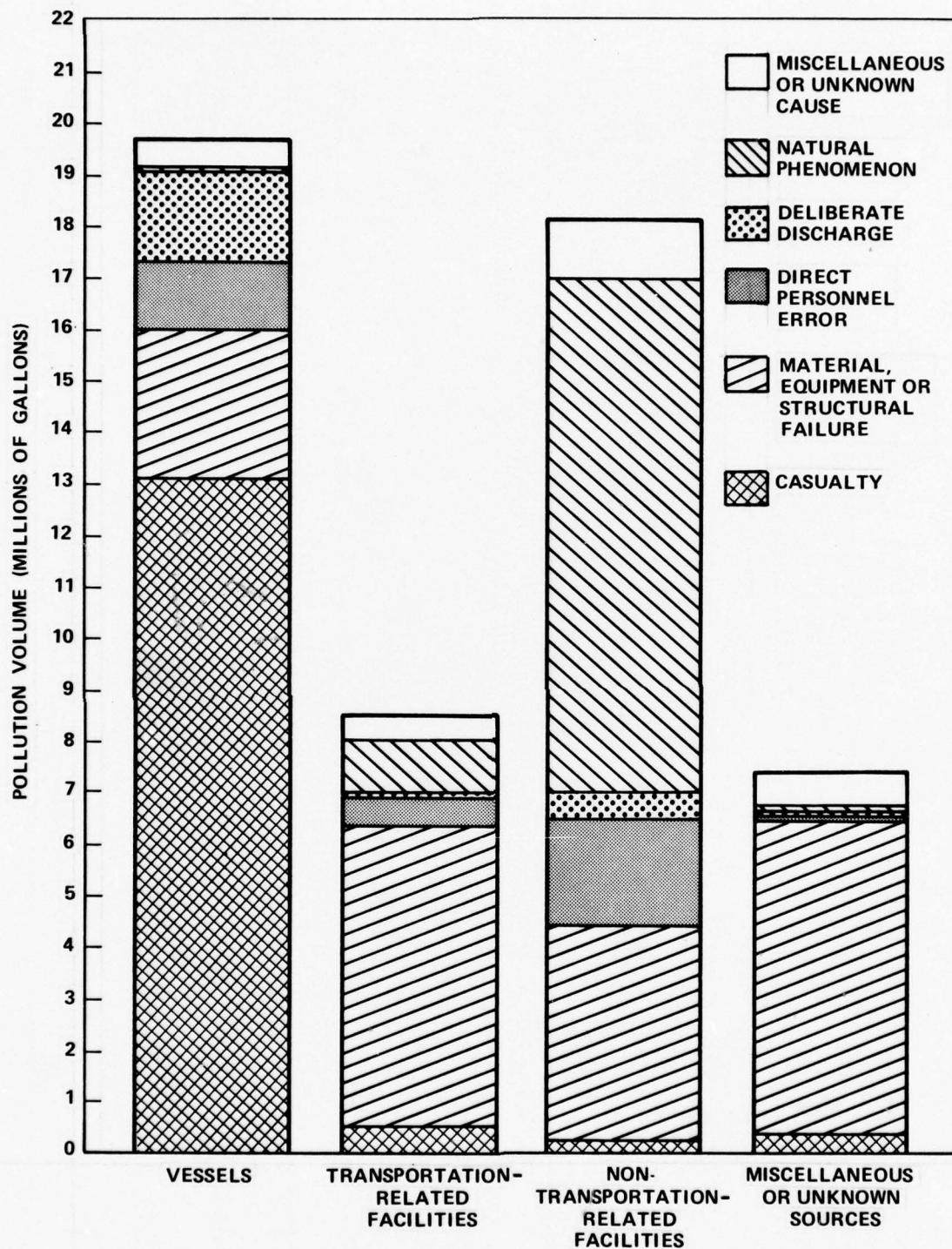


FIGURE 3. POLLUTION VOLUME REPORTED BY PIRS: 1971-1973
BY GENERAL SOURCE AND CAUSE

Eliminating these observations leaves a useful "population" of 44,050,000 gallons discharged in incidents for which both source and cause were known. Table 1 shows the frequency distribution of this volume by general source and cause. The largest source/cause combination is vessel casualties, which accounted for 297 of every 1,000 gallons spilled (29.7 percent of the 44,050,000 total, about 13,070,000 gallons). ^{2/} The second most important contribution to pollution is natural phenomena (storms, earthquakes, etc.) effecting non-transportation-related facilities. This source-cause combination produced 228 of each 1,000 gallons recorded. As pointed out earlier, however, the Coast Guard does not have regulatory jurisdiction over this source, and little can be done immediately to prevent this cause. The prospect of Coast Guard management making appreciable inroads in reducing pollution from this sector are, therefore, severely limited for the present.

In contrast to vessels, where the most important causal group is that of casualty, the most important cause of pollution from transportation-related facilities is failure in structure or equipment, mainly the latter. Such failures accounted for 13.3 percent of overall volume. It is also noteworthy that natural phenomena have had a much lesser impact on transportation-related facilities than on other kinds of facilities. Although it is not apparent as to why transportation facilities should be less vulnerable to natural phenomena, the PIRS data show that the proportion of pollution incidents from such facilities attributable to this cause has been significantly smaller than from non-transportation facilities: only 100 of the 4,153 pollution incidents from transportation-related facilities (2.4 percent) were caused by natural phenomena compared to 337 of 7,733 (4.9 percent) of incidents from non-transportation-related facilities. ^{3/} For both kinds of facilities, the potential for catastrophic spills as a consequence of natural phenomena is evident, with individual spills of 2,000,000 and of 8,000,000 gallons from non-transportation-related facilities, and one of 1,000,000 gallons from a transportation-related facility, having been produced by this cause during the three-year study period.

Taken together, the three general source/cause combinations—vessel/casualty (29.7 percent); non-transportation-related facility/natural phenomenon (22.8 percent); and transportation-related facility/material, equipment or structural failure (13.3 percent)—account for nearly two-thirds of all of the pollution volume recorded by the PIRS where both source and cause were identified. These same source/cause combinations accounted for only 3.5 percent, 1.8 percent, and 15.8 percent of the 18,461 incidents for which source and cause were known.

^{2/} Assuming that the distribution of the unknown group is roughly proportionate and that no significant portion of the actual volume of pollution is going undetected by the PIRS, the total volume spilled in vessel casualties averaged between five and six million gallons per year during the study period.

^{3/} A statistical test (using the standard normal distribution) of the null hypothesis $p_{N-T-R} = p_{T-R}$ (at $\alpha = 0.05$) against the alternative hypothesis $p_{N-T-R} > p_{T-R}$ leads to acceptance of the alternative.

TABLE 1
FREQUENCY DISTRIBUTION: 1971-1973 SPILLAGE VOLUME REPORTED
IN PIRS, BY GENERAL SOURCE AND CAUSE

Cause Source		Casualty	Material, Equipment or Structural Failure	Direct Personnel Error ^{1/}	Deliberate Discharge	Natural Phenomenon	Total Known Cause	Unknown Cause	Total Reported
Vessel Transportation-related facility ^{2/}		29.7	6.6	3.1	4.0	....	43.4	1.2	44.5
		1.2	13.3	1.0	.1	2.4	19.1	1.2	19.3
	Subtotal, DOT jurisdiction	30.9	19.9	4.1	4.2	2.4	61.5	2.3	63.8
	Subtotal, USOC jurisdiction	29.7	11.3	3.6	4.0	2.3	50.9	1.6	52.4
	Non-transportation-related facility ^{2/}	.4	9.9	4.5	.9	22.8	38.5	2.7	41.2
Total, known source		31.3	29.9	8.6	5.1	25.2	100.0 ^{3/}	5.1	105.1
Unknown or miscellaneous source		.4	14.0	.1	.1	....	14.9	1.9	16.8
Total, reported		31.9	43.8	8.7	5.3	25.3	114.9	7.0	121.9

^{1/} The reporting format in use during most of the period does not permit identification of the extent to which personnel error may have been a contributing factor in pollution attributed to other causes.
^{2/} As defined by EPA-DOT Memorandum of Understanding dated 24 November 1971.
^{3/} The total volume of pollution recorded in incidents where both source and cause were identified was 44,050,000 gallons.

PREVENTABLE CAUSES FROM SOURCES WITHIN USCG JURISDICTION

By formal agreement entered into by the Department of Transportation, Coast Guard regulatory jurisdiction excludes those facilities not related to marine transportation. For purely pragmatic reasons, those spills caused by natural phenomena may also be considered beyond the scope of effective Coast Guard influence. Taking these factors into account, Coast Guard resources would be most productively focused on that part of the pollution problem (51 percent of volume; 42 percent of incidents) arising from preventable causes affecting vessels and marine transportation-related facilities (see Figure 1). Table 2 shows the distribution by volume of pollution from sources within DOT jurisdiction. U.S. Coast Guard jurisdiction covers all areas of DOT jurisdiction shown with the exceptions of vehicles and pipelines,^{4/} or about four-fifths of the volume under DOT jurisdiction.

Nearly three of every four gallons spilled were attributed to vessels, with almost 90 percent of the volume spilled by vessels coming from tank ships or tank barges. The one gallon in four originating from a transportation-related facility was 10 times as likely to come from one onshore as from one offshore. Pipelines were the leading sources of pollution among transportation-related facilities, but accounted for less than one-fourth as much volume as tank vessels.

The importance of vessel casualties appears even more salient after the constraints of jurisdiction and preventability have been applied to the data. Sixty-one percent of all of the volume from preventable causes within Coast Guard jurisdiction came from this source/cause combination. Vessel casualties are examined more closely in Section V. Here it will merely be noted that collisions, including those involving fixed objects (rammings), were responsible for nearly half of the pollution from vessel casualties, with the other half approximately evenly divided between capsizings, groundings, and sinkings or foundering. Fires, explosions and all other kinds of accidents accounted for less than four percent of the volume discharged in vessel casualties.

For marine facilities, the casualty cause group has been far less significant than for vessels. Barely one gallon in 1,000 spilled from a marine facility was caused by a casualty event. In contrast to the 582 gallons of every thousand spilled which vessel casualties produced, marine facility casualties produced only 0.1. Eighty-five percent of the pollution produced by all transportation-related facilities was caused by material, equipment, or structural failure. This source/cause accounted for 226 of each 1,000 gallons spilled—twice the amount resulting from the same kind of failures aboard vessels. The majority of the material, equipment, or structural failures at transportation-related facilities were associated with hoses, pipes, and lines.

^{4/} The Coast Guard now has the authority to promulgate prevention regulations for pipelines under a 1974 amendment to Section 311 (j) of the FWPCA. This is a residual jurisdiction where actions of other agencies are inadequate to meet the intent of Congress in regard to water pollution prevention. For the period under study, the Coast Guard did not exercise authority over pipelines.

TABLE 2
FREQUENCY DISTRIBUTION: 1971-1973 PREVENTABLE SPILLAGE VOLUME
FROM SOURCES WITHIN DOT JURISDICTION

Cause Source	Casualty			Material, Equipment or Structural Failure				Direct Personnel Error	Deliberate Discharge	Total Preventable
	Collisions	Capsize or Overturning	Grounding	Other	Subtotal	Tank	Hose, Line or Pipe	Pump or Valve	Other	Subtotal
Tank ship or barge										
< 10K	2.4	...	1.4	...	3.7	...	.2	...	.5	.7
10-100K	7.4	...	1.2	...	8.7	...	.1	...	.2	.4
> 100K	...	...	...	...	...	...	...	...	...	...
Unknown displacement*	10.8	7.8	6.2	5.5	31.3	.5	.5	.2	8.6	9.8
Other vessels	3.4	...	.2	2.9	6.5	...	.1	...	.1	.2
Subtotal, vessels	24.0	7.8	9.0	9.4	50.2	.6	.8	.3	9.4	11.1
Onshore facility										
Marine	...	...	...	...	...	2.1	2.0	.1	3.7	7.9
Pipeline	.3	...	...	...	.3	...	10.2	...	1.3	11.5
Vehicle	.4	1.2	...	.1	1.6	.2	.1	.2	.2	.6
Offshore facility										
Marine	...	...	...	...	...	...	.1	...	...	.1
Pipeline	.1	...	...	...	.1	...	2.3	.1	...	2.4
Subtotal, facilities	.7	1.2	...	.1	2.1	2.3	14.7	.4	5.2	22.6
Total, DOT jurisdiction	24.7	9.0	9.0	9.6	52.3	2.8	15.5	.7	14.7	33.7
									7.1	100.0

* Displacement was not recorded during 1971 and 1972.

** The total volume of pollution recorded in incidents where the cause was "preventable" (i.e., other than a natural phenomenon) and the source was within DOT jurisdiction was 26,020,000 gallons.

Note: (...) indicates less than 0.05.

Direct personnel error was the cause of about seven percent of the volume spilled from both vessels and transportation-related facilities. ^{5/} Vessels, on the other hand, were much more guilty of deliberately discharging pollutants, producing 30 gallons for each gallon discharged by a transportation-related facility. Although permission may sometimes be granted by the responsible regulatory agency for a small intentional discharge to be made, only nine of the 1,007 incidents of deliberate discharge from vessels and transportation-related facilities were, in fact, carried out under Corps of Engineers or EPA permit; 998 were in direct violation of the law. ^{6/} The average volume of illegal discharges was about 2,800 gallons. Under the doubtful assumption that no significant number of illegal discharges are escaping detection, these offenses still produce at least 1,400,000 gallons of pollution each year.

FROM POLLUTION EVENT TO POLLUTION INCIDENT

For a pollution "event" to become a documented pollution "incident," it must be brought to the attention of the personnel charged with maintaining the PIRS. Earlier, it was noted that in a majority of cases the Coast Guard was alerted to the occurrence of a pollution event by the person or organization responsible for the spill. In two instances of 10, the Coast Guard itself was the first to detect a spill. In two more instances, it was detected and reported by a commercial entity or private party other than the "spiller". And in about one instance of 10, the Coast Guard was notified that a pollution event had taken place by another federal, state, or local governmental agency. Only about eight percent of these other governmental reports or about .6 of one percent of the total were received from the EPA (see Appendix C, page C-24).

The means by which the Coast Guard discovered that a pollution event had occurred varied a great deal from the above averages according to the source of the spill. As indicated in Table 3 better than nine out of 10 of the incidents emanating from offshore facilities, whether transportation-related or not, were reported by the party responsible for the spill. Only seven percent of the incidents arising from transportation-related offshore facilities, and three percent of the much larger number of incidents arising from non-transportation-related offshore facilities, were detected and reported by agencies or persons other than those responsible for the spill. By comparison, 62 percent of incidents involving vessels, and more than 50 percent of incidents involving on-shore facilities, were reported by the spiller himself.

^{5/} The importance of personnel error as a possible contributing factor in pollution attributed to other causes in the PIRS records should be kept in mind.

^{6/} Another 65 permits for deliberate discharges (averaging 1,400 gallons apiece) were granted to non-transportation-related facilities. An additional 260 illegal discharges were recorded from these facilities.

TABLE 3
DISTRIBUTION OF 1971-1973 POLLUTION INCIDENTS BY NOTIFIER
(Each Entry Represents a Percentage of Column Total)

Source Notifier	Vessels	Transportation-Related Facilities		Non-Transportation- Related Facilities		Overall
		Onshore	Offshore	Onshore	Offshore	
Offender	62	51	93	46	97	53
USCG	17	19	2	30	1	19
EPA or other government agency	7	19	1	1	1	9
Other commercial entity or private party	<u>14</u>	<u>11</u>	<u>4</u>	<u>13</u>	<u>1</u>	<u>19</u>
Total	100	100	100	100	100	100*

* Represents 15,376 incidents for which information as to the notifier was recorded (approximately 48 percent of the total of 32,072 incidents reported during the three-year period).

It is also interesting to note that the largest percentage of incidents wherein the Coast Guard detected the spill is associated with non-transportation-related onshore facilities. Thirty percent of the incidents reported from this general source were detected by the Coast Guard, compared to less than 20 percent of the incidents involving vessels or transportation-related facilities, despite the fact that most of the latter are within the Coast Guard's regulatory jurisdiction and the former are not. To the extent that the fraction of incidents attributed to Coast Guard detection is a function of the intensity of its surveillance activities, these statistics are contrary to what would be expected.

Another explanation for the comparatively high input of Coast Guard reports for non-transportation-related facilities could be that these sources are adhering less rigorously to self-reporting of pollution events, leaving a greater portion of events that occur to be detected first by the Coast Guard. Similarly, the very low input of reports from other government agencies (less than one percent for non-transportation-related onshore facilities as opposed to 19 percent for transportation-related onshore facilities) could signify a double counting that might serve to inflate the Coast Guard input (i.e., state and local government agencies may be reporting some of the spills from non-transportation facilities to other federal agencies which are later "re-detected" by the Coast Guard). More research is needed to affirm the proper interpretation on this point.

The differences in the distributions of "notifier" among alternative sources could pose questions concerning the completeness of the data being collected in the PIRS. The key issue here is that of potential under-enumeration and the biases this could produce if it varies among different source/cause combinations. Figure 4 illustrates in simplified form the sequences by which a pollution event may be brought to the attention of the PIRS, thereby being transformed into a pollution incident. Data are not adequate to permit the estimation of the values of the terms depicted in the figure at this time.

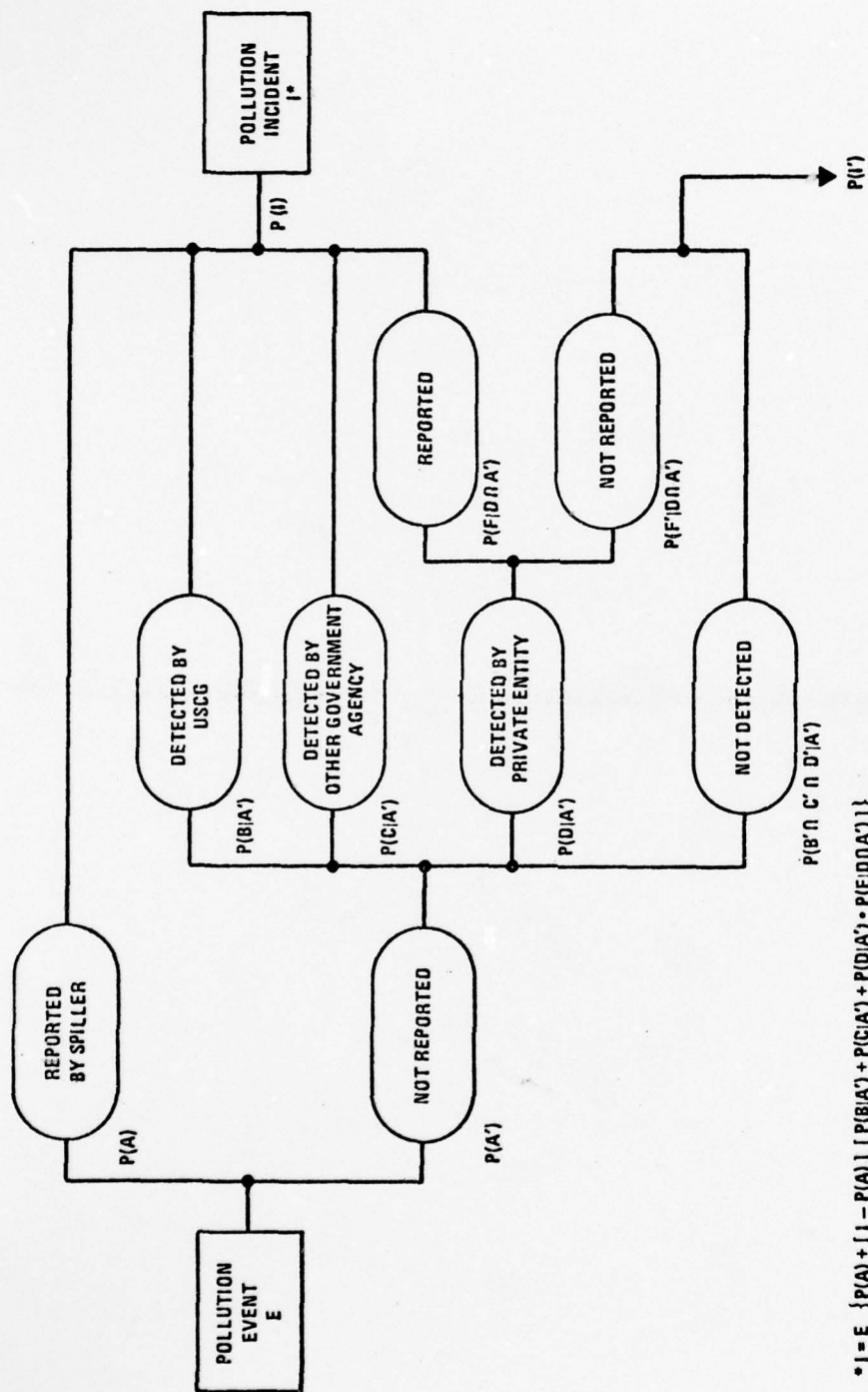


FIGURE 4. PROBABILITY SEQUENCE: POLLUTION EVENT TO POLLUTION INCIDENT

IV. VARIATIONS IN THE SEVERITY OF POLLUTION INCIDENTS

AVERAGE SPILLS FOR GENERAL SOURCE/CAUSE COMBINATIONS

The distribution of the average volumes of pollutants released per pollution incident reflects a high variance among various source and cause groupings (see Figures 1 and 2 for definition of the classification system). This distribution is shown in Table 4.

Within the area of greatest management interest to the Coast Guard, i.e., where the cause was preventable and the source was within USCG regulatory jurisdiction, by far the largest spills were associated with casualties to vessels. This produced an average discharge of nearly 30,000 gallons compared to an average of less than 1,400 gallons for all other source/cause combinations within the Coast Guard's jurisdiction. Casualties involving marine transportation facilities resulted in an average spill of less than 200 gallons. Failure of some material or structural component or article of equipment, the most important cause of preventable pollution from marine transportation-related facilities, resulted, on the average, in release of only 3,300 gallons. Deliberate discharges from vessels averaged 3,000 gallons, fourteen times the average volume released from marine transportation-related facilities in this kind of incident.

Since the severity of the pollution that can be expected to be produced by different combinations of sources and causes can provide essential insights into how best to allocate preventive resources, it is worthwhile to examine the averages summarized in Table 4 in greater detail.

TABLE 4
AVERAGE QUANTITY SPILLED PER POLLUTION INCIDENT: * 1971-1973
(Thousands of Gallons)

Source	Cause	Casualty	Material Equipment or Structural Failure	Direct Personnel Error	Deliberate Discharge	Overall, Preventable Cause	Natural Phenomenon	Overall, Known Cause
Vessel		29.6	1.4	0.5	3.0	3.4	0.1	3.4
Transportation-related marine facility**		0.2	3.3	0.7	0.2	2.2	33.9	3.1
Overall, USCG jurisdiction		28.6	1.9	0.5	2.9	3.2	12.5	3.3
Pipeline or vehicle		2.8	1.8	0.8	1.0	1.8	0.9	1.7
Overall, DOT jurisdiction		21.0	1.8	0.6	2.7	2.8	8.8	2.9
Non-transportation-related facility**		2.4	0.8	1.8	3.0	1.0	45.3	2.5
Overall, known source		19.2	1.3	0.9	2.8	2.1	32.5	2.7
* Excludes incidents where quantity spilled was not recorded (12 percent of total incidents where both source and cause were identified).								
** As defined by EPA-DOT Memorandum of Understanding dated 24 November 1971.								

CONTRASTS IN THE DISTRIBUTIONS OF INCIDENTS AND VOLUME

One of the most striking features to emerge from the PIRS data is the extent to which the pollution problem has originated from a comparatively few causes acting upon an equally small number of sources. This is true regardless of which indicator—volume or incidents—is deemed to more accurately measure the scale of the problem (although focus shifts dramatically from one set of source/cause combinations to another according to the selection). In order to illustrate these points, the two general groups of sources within USCG jurisdiction (vessels and transportation-related facilities) and the two most important groups of related causes (casualties and material structural or equipment failures) have been broken down into the smaller, more specific categories indicated below. Of the 70 theoretical combinations of the seven sources and 10 causes shown, six (such as offshore pipeline-capsize, or onshore marine facility-grounding) are essentially meaningless in a pragmatic sense.

<u>Source</u>	<u>Cause</u>
1. Tank ship or barge	1. Collision (including rammings)
2. Other vessel	2. Grounding*
3. Onshore marine facility	3. Capsize or overturning*
4. Onshore pipeline	4. Fire, explosion, or other casualty
5. Vehicle	5. Tank failure
6. Offshore marine facility	6. Hose, pipe, or line failure
7. Offshore pipeline	7. Pump or valve failure
	8. Other material, equipment or structural failure
	9. Direct personnel error
	10. Deliberate discharge

* Not relevant to onshore marine facilities or pipelines (onshore or offshore).

Of the 64 viable source/cause combinations at this level of definition, 42, or just about two-thirds, failed individually to account for either two percent of the volume or two percent of the incidents which were recorded—an arbitrary criterion for significance employed in this study. ^{1/}

^{1/} Establishing a four percent criterion would reduce the number of significant source/cause combinations from 22 to 10.

Taken together, this group made up only 5.3 percent of volume and 12.7 percent of incidents reported. A scatter diagram showing the relative importance of each of the 22 remaining source/cause combinations in terms of both contribution to volume and contribution to incidents reported is presented in Figure 5.

Very few source/cause combinations fall near the 45° line indicative of equal contributions to both volume and reporting incidence. To the contrary, the source/cause combinations which rank the highest in volume tend to rank quite low in incidence, and those which rank high in incidence play only a minor role in accounting for volume spilled.

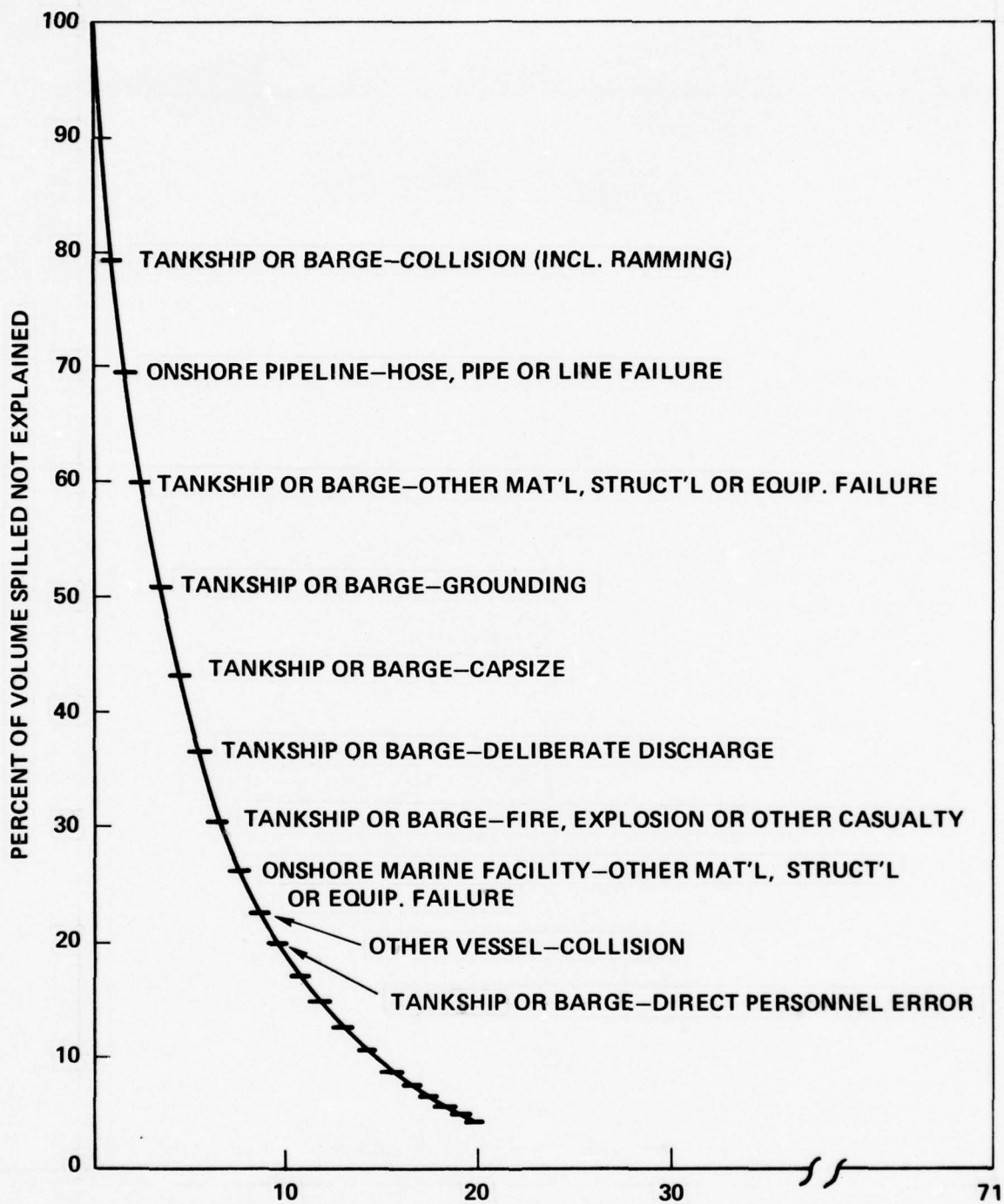
Among the seven source/cause combinations which contribute more than six percent each to volume spilled, only one—tank ship or barge/other material, structural or equipment failure—ranks above the six percent line in incidence as well. The leading contributor to volume, tank ship or barge/collision, constituted only 1.3 percent of incidents reported. Conversely, the three highest contributions in terms of the number of incidents reported (offshore pipeline/hose, pipe, or line failure; tank ship or barge/direct personnel error; and other vessel/direct personnel error) in each case contribute only two to three percent to volume spilled.

In Figure 6, the portion of total volume spilled as a consequence of preventable causes acting on sources within USCG regulatory jurisdiction that remains "unexplained" is plotted against the number of source/cause combinations that are considered (starting with the biggest contributor to volume, then the second biggest and so forth). One source/cause combination, collisions (including rammings) involving tank ships or barges, alone "explains" over 20 percent of the total volume spilled. Only 10 of the 21 viable source/cause combinations need be considered to identify the origin of 80 percent of total volume. Beyond this point, contribution to volume spilled falls off rapidly. Doubling the number of source/cause combinations that are considered to 20 only explains an additional 15 percent of the total volume. The remaining five percent was produced by all of the other 51 source/cause combinations together.

Among the 10 foremost source/cause contributors to pollution volume, seven involve tank ships or barges as the source component. Only two involve transportation-related facilities, and in both of these cases the cause is some kind of failure in material, structure or equipment rather than a casualty.

IMPLICATIONS FOR COAST GUARD OPERATIONS

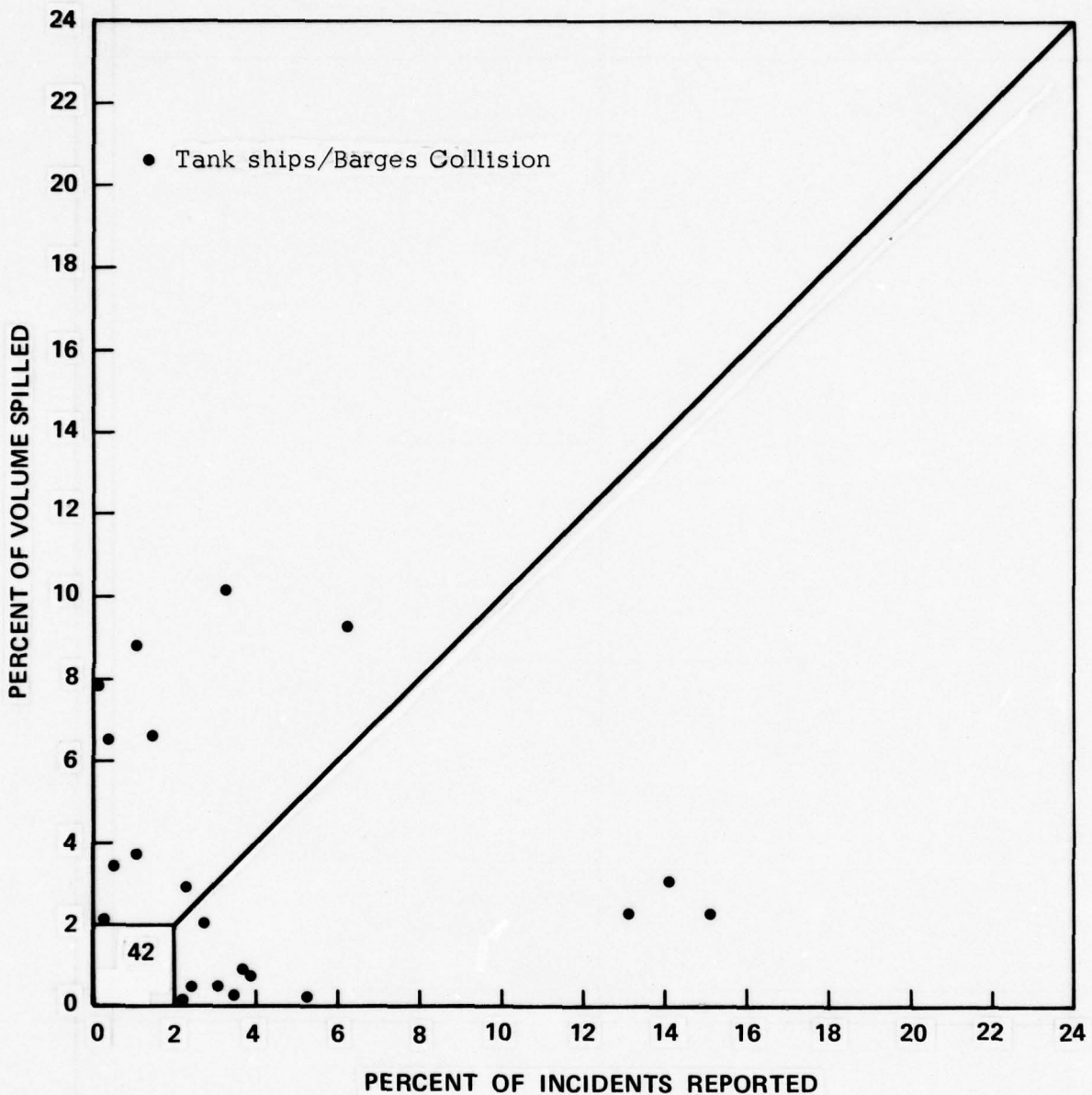
Under current policy, Coast Guard personnel are required to investigate, and the PIRS system is required to record and process, every pollution



NUMBER OF EXPLICIT SOURCE/CAUSE COMBINATIONS CONSIDERED

* FOR PREVENTABLE CAUSES WITHIN USCG REGULATORY JURISDICTION

FIGURE 5. PERCENT OF VOLUME NOT EXPLAINED VS NUMBER OF EXPLICIT SOURCE/CAUSE COMBINATIONS CONSIDERED*



*DEFINED HERE AS THOSE COMBINATIONS RESPONSIBLE FOR AT LEAST TWO PERCENT OF TOTAL VOLUME AND/OR TOTAL INCIDENTS REPORTED. TWENTY-TWO OF THE SIXTY - FOUR POSSIBLE COMBINATIONS OF PREVENTABLE CAUSES AND SOURCES WITHIN USCG JURISDICTION MEET THIS CRITERION.

FIGURE 6. CAUSE PREVENTABLE AND SOURCE WITHIN USCG JURISDICTION: PERCENT OF VOLUME VS PERCENT OF INCIDENTS REPORTED FOR PRINCIPAL SOURCE/CAUSE COMBINATIONS, 1971-1973*

incident that is brought to their attention regardless of the volume of pollutants released. ^{2/}

Although these guidelines were sound when the PIRS was introduced in 1970, since little was known at that time about the parameters of the pollution problem, the experience gained over the past few years suggests that revisions might now be seriously contemplated. The basis for this conclusion emerges vividly in Figure 7 which plots the probability that an incident reported by PIRS involved a discharge of a given size (up to 100,000 gallons) against the probability that a gallon of pollution selected at random from the 26,020,000 gallons that originated from preventable causes within Coast Guard jurisdiction came from an incident of that size. The plots reflect two distributions extremely skewed, but in opposite directions.

Whereas the median spill for pollution incidents (i.e., that volume which was exceeded in one-half of the incidents reported) was less than 20 gallons, the median for spillage was over 800,000 gallons (i.e., half of all the volume spilled came from incidents involving discharges in excess of this magnitude). Similarly, 94.4 percent of all of the incidents recorded involved a discharge of less than 1,000 gallons. But these same incidents accounted for only a very minor 2.1 percent of the total volume of pollution that was released.

The issue these statistics pose, then, is whether the Coast Guard should continue to devote resources to investigating, recording and processing small spills in view of the miniscule role such spills play in contributing to pollution volume. Without a detailed inquiry into the extent of the costs involved in these activities, the argument nonetheless appears strong that a more cost-effective overall allocation of resources would likely result if the effort now consumed in monitoring small spills were redirected to concentrate on prevention of incidents from source/cause combinations that are major contributors to pollution volume. The most feasible cut-off level might well prove to be 1,000 gallons (or its equivalent if the material discharged is commonly measured in pounds, which would account for 97.9 percent of spill volume although disregarding all spills under 10,000 gallons would still leave 90 percent of the overall pollution problem as measured by total volume discharged. (Note Figure 7).

One argument that might be put forth for continuing to investigate and record every incident is the deterrent effect this careful scrutiny could have on potential sources of pollution. That is, by demonstrating an attentiveness to even very small pollution incidents, the Coast Guard might encourage attitudes and practices among potential polluters which would diminish the

^{2/} In fact, the PIRS coding instruction manual directs that no actual pollution need occur for an incident report to be filed. The existence of conditions which "threatened to discharge" is sufficient in itself to warrant an incident report. In practice, few of these potential pollution incidents are processed.

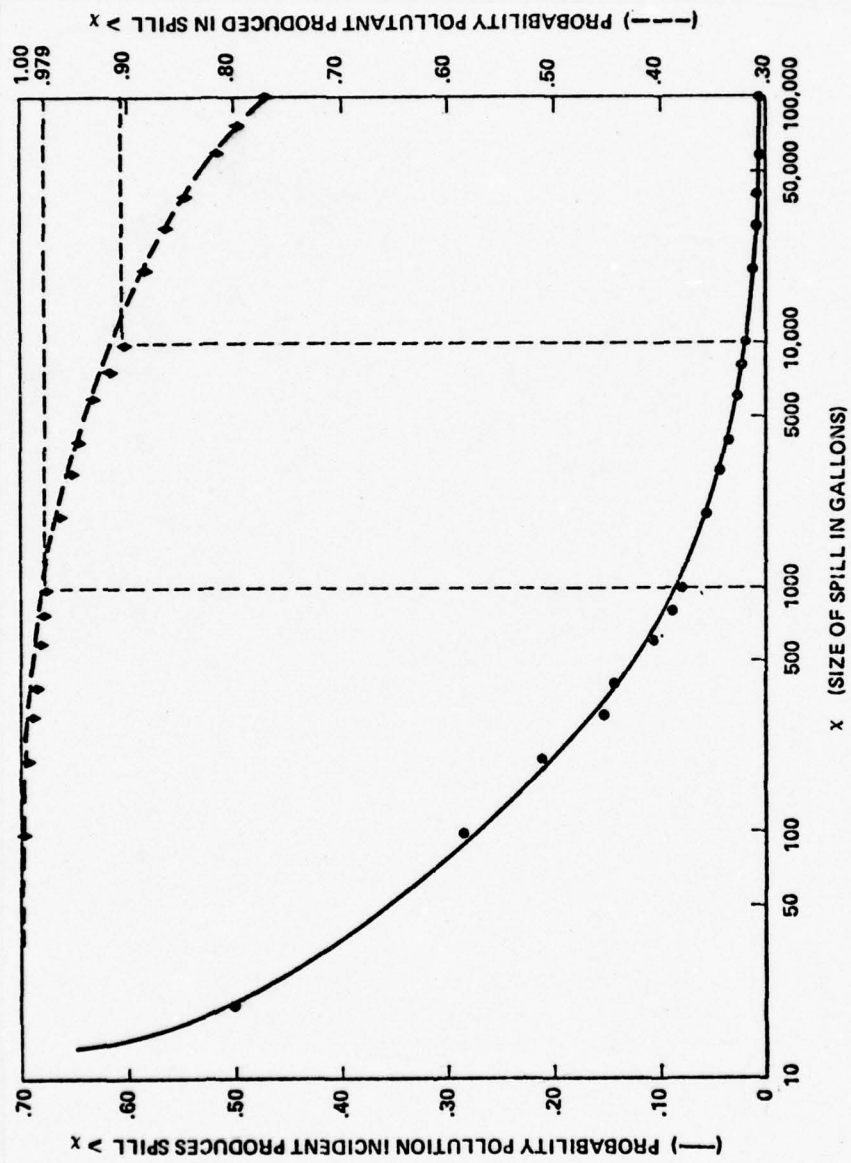


FIGURE 7. POLLUTION INCIDENTS AND POLLUTION PRODUCED
VS SIZE OF SPILL

likelihood of conditions developing which could lead to larger spills. As has been demonstrated, however, the sources and causes of large spills are different from those from which the masses of small incidents arise. It is unlikely, for example, that continuing to thoroughly investigate every small spill produced by the grounding of a recreational craft would much serve to deter the very large spills produced by the capsizing of tank barges, or that carefully monitoring incidents of hose or line failures at an offshore facility would have much influence on the 20 times larger spills associated with the same cause in onshore pipeline systems.

Assuming Coast Guard operating resources were redirected to concentrate on preventing the larger spills, the question would still remain as to where inspectors should look, and for what dangers, in order to use their time most productively in combating pollution volume. One method for deriving such guidelines employs the concept of "expected payoff". Perhaps the best way to illustrate this notion is by posing the following question: If the Coast Guard could prevent but one pollution incident a year, what kind of incident should it be in order to have the maximum expected impact in lowering pollution volume over the next decade? It has been shown that tankships and barges are the most important source of pollution. But the pollution incident that does not occur because an alert inspector detects a faulty valve on a tank barge would not be likely to have much influence on total volume. The pollution discharged by the failure of this kind of component averages less than 200 gallons.

By contrast, if the same inspector were to detect conditions which threatened to capsize the same tank barge, the expected payoff for his taking the measures required to prevent that occurrence would be many times greater. In fact, over the long-run preventing the capsize of a tank barge would be the most productive choice that could be made in answer to the hypothetical question posed (even though the infrequency of such events would mean that in some years no incidents at all would be prevented because none were destined to occur).

Table 5 utilizes "payoff factors"^{3/} to rank significant (i.e., those that account for at least two percent of either total volume or total incidents) explicit source/cause combinations according to the impact that a one incident

^{3/} The factors represent the multiple of the average overall payoff (reduction in pollution volume) associated with preventing a pollution incident that would be expected if the incident came from the stated source and cause. In other words, the payoff factor is the ratio of the percentage of total volume spilled to the percentage of total incidents involved (e.g., a source/cause combination which accounted for 20 percent of volume spilled and 5 percent of incidents would have a payoff factor of 4.0). Since the average volume spilled for all incidents from preventable cause within DOT jurisdiction was about 2,800 gallons, the expected payoff in, for example, preventing an incident involving tank failure at an onshore marine facility (a source/cause combination with a payoff factor of 7.2) would be on the order of 20,000 gallons. Similarly, the payoff to preventing deliberate discharge from vessels other than tank ships or barges (payoff factor .04) would average only about 100 gallons for each incident prevented.

TABLE 5

PAYOFF FACTORS FOR SIGNIFICANT COMBINATIONS OF PREVENTABLE
CAUSES FROM SOURCES WITHIN DOT JURISDICTION

$$\text{Payoff} = \frac{\frac{\text{Volume}}{\sum \text{Volume}}}{\frac{\text{Incidents}}{\sum \text{Incidents}}} = \frac{\% \text{ Volume}}{\% \text{ Incident}}$$

Payoff Rank	Source/Cause Combination	Volume		Incidents		Payoff* Factor
		Percent	Rank	Percent	Rank	
1	Tank ship or barge—capsize	7.8	5	(4)**	52	179.7
2	Tank ship or barge—fire, explosion, or other casualty	6.5	7	0.4	34	18.2
3	Tank ship or barge—collision	20.6	1	1.3	18	18.1
4	Tank ship or barge—grounding	8.8	4	1.1	21	11.6
5	Other vessel—collision	3.4	9	0.5	31	8.8
6	Onshore marine facility—tank failure	2.1	14	0.3	37	7.2
7	Tank ship or barge—deliberate discharge	6.6	6	1.5	16	5.7
8	Onshore marine facility—other material, equipment, or structural failure	3.7	8	1.1	23	3.8
9 ¹	Onshore pipeline—hose, pipe, or line failure	10.2	2	3.3	9	3.0
10	Other vessel—fire, explosion, or other casualty	2.9	11	2.3	13	1.7
11	Tank ship or barge—other material, equipment, or structural failure	9.3	3	6.2	4	1.5
12	Onshore marine facility—hose, pipe, or line failure	2.0	15	2.8	11	0.69
13	Onshore marine facility—direct personnel error	0.9	18	3.7	7	0.25
14 ¹	Vehicle—direct personnel error	0.5	20	2.4	12	0.24
15	Tank ship or barge—direct personnel error	3.1	10	14.1	2	0.22
16	Tank ship or barge—hose, pipe, or line failure	0.8	19	3.8	6	0.19
17	Tank ship or barge—tank failure	0.5	21	3.1	10	0.18
18	Other vessel—direct personnel error	2.1	13	13.3	3	0.16
19 ¹	Offshore pipeline—hose, pipe, or line failure	2.3	12	15.1	1	0.15
20	Tank ship or barge—pump or valve failure	0.3	22	3.5	8	0.08
21	Other vessel—other material, equipment, or structural failure	0.1	24	2.2	14	0.04
22	Other vessel—deliberate discharge	0.2	23	5.3	5	0.04

* Multiple of average (overall) quantity spilled for all incidents where cause was preventable and source was within DOT jurisdiction. Computations exclude incidents where quantity spilled was not recorded.
Payoff factor = $\frac{v \sum v}{i \sum v}$.

** The four cases of barges capsizing which were recorded during the three year period represent a trivial percentage of total incidents. A 2,000,000 gallon discharge in 1971 and a 250,000 lb. discharge in 1972 due to barge capsizings can not be substantiated by case files at the 8th CG District.

¹ Not under USCG jurisdiction.

reduction would be expected to have on the overall volume of pollution arising from preventable causes acting on sources within USCG jurisdiction. The most lucrative areas are those with the highest payoff factors.

If every incident of every kind was equally difficult (i.e., costly in terms of Coast Guard operating and administrative resources) to prevent, the optimum management strategy would simply be to start at the top of Table 5, and work down, disregarding lower ranking source/cause combinations until adequate resources had been allocated to reduce the incidence of every combination with a higher payoff factor to zero. Obviously, this is not actually the case. ^{4/} Not only is the cost of prevention apt to vary among incidents arising from different sources and causes, it also will vary within a source/cause combination. (Reducing the incidence of hose, pipe, or line failure by 90 percent could, for example, require much more than nine times the effort of achieving a 10 percent reduction.)

A thorough analysis of costs and methods is, therefore, required before specific management principles governing the Coast Guard's surveillance and regulatory efforts can be formulated. In the absence of such information, the computations summarized in Table 5 cannot be accepted unequivocally. The "payoff factor" approach may, nonetheless, provide basic insights into the direction in which the Coast Guard's limited preventive resources might most productively be applied.

^{4/} See Section VI for additional comments on optimizing the allocation of preventive resources.

V. VESSEL CASUALTIES

In Section II, it was noted that casualty to vessels is by a considerable margin the most important contributor to pollution volume, accounting for nearly 30 percent of what was reported from known sources and causes within USCG regulatory jurisdiction as a consequence of theoretically preventable causes. Moreover, the five highest payoff factors (see Table 5) are all associated with a vessel casualty of one kind or another. In this section, vessel casualties are extracted from the general population of pollution incidents and examined in detail to determine more specifically the kinds of vessels which figure most prominently in pollution discharges, the accidents in which they are most often involved, and the severity of the pollution that may be expected to result.

THE DISTRIBUTION OF VOLUME FROM VESSEL CASUALTIES

During the 1971-1973 period, vessel casualties were responsible for discharging 13,067,000 gallons of pollution in recorded incidents. The distribution of this volume among various kinds of vessels according to the kind of accident which beset them is shown in Table 6. Not surprisingly, tank barges and tank ships were by far the worst polluters, accounting for nearly 9 out of 10 gallons discharged. Dry cargo vessels have been inconsequential polluters, and all other classes have played comparatively minor roles as well. Because of their greater vulnerability to sinking, foundering, and capsizing, (tank ship incidents in these categories were negligible), tank barges accounted for a larger share of volume from vessel casualties than did tank ships. However, the largest single contribution arose from tank ship collisions (including ramming): one of each four gallons spilled in all vessel casualties. Collisions involving other classes of vessels (primarily tank barges) produced nearly as much volume as tank ship collision. Since, taken together, vessel collisions

TABLE 6
VESSEL CASUALTIES: DISTRIBUTION OF POLLUTION VOLUME FOR 1971-1973
(Percent)

Vessel Type	Collision ^{1/}	Grounding	Capsizing	Fire or Explosion	Sinking or Foundering	All Other Casualties	Total for Vessel Class
Tank ship	24.8	9.3	... ^{2/}	...	...	...	34.1
Tank barge	16.3	8.2	15.5	...	12.9	...	53.0
Dry cargo vessel	...	...	...	...	...	...	...
Dry cargo barge	...	...	...	3.0	...	0.5	3.6
Towboat/tugboat	4.1	...	...	...	...	...	4.2
All other vessels	<u>2.7</u>	<u>...</u>	<u>...</u>	<u>...</u>	<u>2.0</u>	<u>...</u>	<u>5.1</u>
Total for cause	47.8	17.9	15.6	3.1	15.2	0.5	^{3/} 100.0

^{1/} Includes collisions with fixed objects (rammings) as well as moving vessels.

^{2/} (...) indicates less than one-half of one percent.

^{3/} Represents 13,067,000 gallons spilled in incidents involving vessel casualties recorded in PIRS.

were responsible for 24 percent of the total volume from preventable cause within USCG jurisdiction, the concentration of Coast Guard research to date in this area appears to have been well founded.

INCIDENCE OF VESSEL CASUALTIES

In contrast to the role of vessel casualties as the foremost contributor to pollution volume, the frequency of such incidents has been quite low. During 1971, 1972, and 1973, a total of 19,226 pollution incidents were recorded that identified both source and cause. Of the 7,368 incidents where the source was within the Coast Guard's jurisdiction, only 655, or slightly more than six percent, involved a vessel casualty.^{1/} Examining these 655 incidents which involved some kind of casualty to some kind of vessel in detail (see Table 7) reveals that in addition to being the biggest contributor to pollution volume, tank barges also tallied the highest number of pollution incidents, well over twice the number associated with tank ships.

Compared to tank ships, which were nearly twice as likely to be involved in a grounding accident as a collision, tank barges were collision prone. The revised PIRS format introduced in 1973 does not differentiate collisions with fixed objects (usually referred to as rammings) from those involving moving vessels. The format in use during 1971 and 1972 did allow this distinction, however. Although both tank ships and tank barges were involved in slightly more ramming incidents than collisions with other moving vessels (8 of 13 tank ship collisions and 40 of 75 barge collisions involved fixed objects), the difference was not sufficient to meet the strict test of statistical significance. Based on the limited data from 1971 and 1972, vessel collisions may be considered as roughly evenly divided between collisions with fixed objects and collisions with other moving vessels. For both tank ships and tank barges, other kinds of accidents such as capsizing, fire, explosion, sinking and foundering occurred infrequently compared to collisions, rammings, and groundings.

It is also interesting to note that although "other vessels" (which includes all fishing, passenger, recreational, combatant, and public ships and boats) accounted for 39 percent of the incidents that were recorded, for vessels, they produced only one gallon in 20 of the pollution discharged by vessels.

^{1/} The large contribution to volume and low contribution to incidents reported accounts for the high payoff factors associated with various kinds of vessel casualties.

TABLE 7
VESSEL CASUALTIES: DISTRIBUTION OF POLLUTION INCIDENTS 1971-1973
(Percent)

Vessel Type	Collision ^{1/}	Grounding	Capsizing	Fire or Explosion	Sinking or Foundering	All Other Casualties	Total for Vessel Class
Tank ship	4.0	7.5	... ^{2/}	0.5	0.5	1.1	13.4
Tank barge	16.3	10.1	0.6	...	2.0	2.0	31.3
Dry cargo vessel	0.8	1.5	...	1.4	0.6	...	4.6
Dry cargo barge	...	...	...	...	1.2	...	...
Towboat/tugboat	1.1	1.4	...	...	6.1	0.2	9.2
All other vessels	<u>5.2</u>	<u>5.6</u>	<u>1.8</u>	<u>2.9</u>	<u>22.9</u>	<u>0.6</u>	<u>39.1</u>
Total for cause	27.6	26.3	3.2	5.5	33.3	4.1	100.0 ^{3/}

^{1/} Includes collisions with fixed objects (rammings) as well as moving vessels.

^{2/} (...) indicates less than one-half of one percent.

^{3/} Represents 655 incidents involving vessel casualties recorded in PIRS.

THE SEVERITY OF POLLUTION INCIDENTS INVOLVING VESSEL CASUALTIES

Whereas the overall average spill for pollution incidents arising from preventable causes acting on sources within USCG jurisdiction was slightly over 3,300 gallons, the average vessel casualty released 29,600 gallons of pollutants. Although tank ships tended to produce larger spills (the average was 80,900 gallons) than other kinds of vessels, it is evident from the data summarized in Table 8 that almost any kind of accident to any kind of vessel holds the potential of discharging a large volume of pollution. In isolated incidents of fire/explosion aboard a dry cargo barge and collision involving tow/tugboats, both types of vessels that generally produced small spills from accidents, large amounts of pollutants were released. And the four cases of tank barge capsizes produced an average spill in excess of 500,000 gallons. Tank ships involved in collision produced much larger spills than those involved in groundings. During 1971 and 1972, tank ships that collided with other moving vessels produced spills that averaged three times greater than those from tank ships that collided with fixed objects. In the case of tank barges, there was little difference in the average spill whether the accident involved collision with another moving vessel, a fixed object, or grounding (the discharge resulting from all three kinds of accidents averaged in the neighborhood of 25,000 gallons).

THE TREND FOR VESSEL CASUALTIES

All of the analysis and conclusions expressed in preceding sections were based on experience acquired in the 1971-1973 period. Needless to say, the question of what will happen in the three year period which lies ahead is of much greater interest than anything which has already transpired. Given that the data accumulated during 1971-1973 were generated by a fleet of tank ships and barges the composition of which is constantly evolving, how applicable are conclusions drawn from this period to the present or the future? Will casualties to vessels of these types continue to dominate the pollution problem to the same extent as they have in the past?

Although it is not possible to forecast precisely the role vessel casualties will play in the future, an appraisal of likely changes in the composition of a key segment of the vessel population—U.S. flag tank ships—in the context of worldwide experience with pollution from tanker accidents suggests that the importance of vessel casualties in contributing to pollution is more likely to increase than decline over the next several years. Almost certainly, excepting whatever inroads may be achieved by regulatory action, pollution volume from vessel casualties will not of its own accord appreciably decrease in the near term. Clearly, there is scant prospect in the near term for vessel casualties being replaced as the foremost contributor to pollution volume by another source/cause combination within Coast Guard jurisdiction. For that to happen, the annual volume produced by the second-ranking contributor to pollution—material, structural or equipment failure at transportation facilities—would have to increase by half, while the volume for vessel casualties fell by a comparable proportion.

TABLE 8
VESSEL CASUALTIES: AVERAGE QUANTITY SPILLED PER POLLUTION INCIDENT
(Thousands of Gallons)

Vessel Type	Collision*	Grounding	Capsizing	Fire or Explosion	Sinking or Foundering	All Other Casualties	Average for Vessel Class (All Causes)
Tank ship	179.7	48.6	N.R.**	0.1	0.1	0.3	80.9
Tank barge	24.4	23.9	506.3	0.1	168.8	0.5	43.8
Dry cargo vessel	0.6	0.7	N.R.	0.1	3.0	0.1	0.5
Dry cargo barge	4.0	N.R.	0.3	199.0	5.6	60.0	59.2
Towboat/tugboat	105.7	1.5	N.R.	0.1	0.4	0.1	12.5
All other vessels	<u>13.6</u>	<u>2.0</u>	<u>1.0</u>	<u>0.7</u>	<u>2.7</u>	<u>0.1</u>	<u>4.2</u>
Average Total for Cause (all vessels)	44.3	24.1	145.2	17.6	13.8	2.9	29.6

* Includes collisions with fixed objects (rammings) as well as moving vessels.

** N.R., no incident reported.

During the decade ending in 1973, the average size, measured in deadweight tons (DWT), of a tanker in the world fleet more than doubled (from 23,200 to 56,300 DWT).^{2/} During the same period, the growth in displacement of tankers with U.S. registry lagged by a wide margin, but nonetheless increased over 50 percent to 30,500 tons. During 1972, the latest year for which data are available, the average displacement of U.S. flag tankers increased 8.2 percent.

Despite the current reduction in worldwide consumption of petroleum products, and the excess of tanker capacity this downturn in demand has produced, the firm orders for new ships that have been already placed assure that the upward trend in the average size of U.S. flag tankers will continue for at least the next several years. At the end of 1973, 62 tankers averaging 82,700 DWT intended for U.S. flag registry were on order or under construction. Under the assumption that these ships are eventually introduced as one-for-one replacements for the oldest privately owned tankers now under U.S. registry, the net effect of their introduction would add nearly 3,800,000 DWT to the fleet, raising the average size of U.S. flag tankers by 45 percent to 51,000 DWT by the end of 1976 or 1977.^{3/}

Of greatest interest in a pollution context is the number of large ships in the tanker fleet. At the end of 1972, there were only two tankers rated in excess of 100,000 DWT registered under the U.S. flag. Two additional ships in this broad displacement class entered service during 1973. At present, only one U.S. terminal has the capacity to accommodate such ships. Hence, there has been scant opportunity (only 3-4 operating ship-years) for the PIRS to accumulate information on the pollution performance of tank ships in this class.^{4/} At the end of 1973, ten new tankers in the 100,000 DWT or greater class were on order or under construction in the U.S. Consequently, the operating exposure of tankers in excess of 100,000 DWT will be well over ten times greater during the period 1975-1977 than it was in 1971-1973.

^{2/} Discussion of the changing composition of the World and U.S. flag tanker fleets reflects authors' interpretation of data presented in: Analysis of World Tanker Fleet, December 1973, a report prepared by the Planning and Industrial Office of the Sun Oil Company, St. Davids, Pennsylvania.

^{3/} Of course, some of the new tankers will actually replace more modern and likely larger vessels. Therefore, the assumption of one-for-one replacement on a "first-in-first-out" basis produces a ceiling, not a maximum likelihood, estimate for fleet growth.

^{4/} Eleven pollution incidents were recorded for tank ships greater than 100,000 gross tons during 1973. All were small incidents (the average spill was less than 100 gallons), however, suggesting the close regulatory attention that has been focused on tankers of this size. No incident involving a casualty, the cause group deserving of the greatest concern, was recorded in U.S. waters during the 1971-73 period.

Some insight into what to expect from the growth in tanker size within the U.S. fleet may be gleaned from experience gained in international operations. Table 9 summarizes the accident record of the world tanker fleet during 1971 and 1972, classed in four broad groups according to deadweight tonnage. Examining the accident experience in terms of the number of polluting incidents weighted by the number of vessels in service, it is apparent that very small tankers, those under 9,000 DWT, were involved in proportionately fewer such incidents (an average of 1.3 annually for every 100 vessels). For vessels in the 10,000-29,000 DWT class, the pollution incident rate jumps sharply to 4.2 per 100 ships per year. Although there appears to be a slight decline in the frequency of pollution incidents as size increases beyond 29,000 DWT, the differences are too small to be conclusively labelled as significant. In terms of the severity of the pollution produced when a tanker has an accident, it is clear, however, that the bigger the vessel, the bigger the spill which can be anticipated. The data indicate a steady progression in the average volume of pollution discharged, from less than 40,000 gallons for accidents involving very small tankers to 1,400,000 for ships displacing more than 100,000 DWT.

Adjusting pollution volume for the varying number of vessels in each class ($\text{Percent of Volume Spilled} \div \text{Percent of Total Tankers}$) indicates that ship-for-ship, a tanker in the 100,000 plus DWT class may be expected to produce four times as much pollution as a tanker in the 10,000-29,000 DWT class. Therefore, if the new U.S. vessels replace older, smaller tankers ship-for-ship, upward pressure on pollution volume would almost certainly be generated.

On the other hand, aggregate deadweight tonnage undoubtedly constitutes a better measure of total demand for the services of tankers than does the number of vessels in the fleet. If the economy's requirements for tankers are viewed in this context, it can be argued that less overall pollution will be produced if larger tankers are employed to satisfy a given level of demand because fewer vessels would be needed. Weighting the worldwide experience with tanker accidents by displacement ($\text{Percent of Volume Spilled} \div \text{Percent of Total Deadweight}$) rather than by number of vessels yields preliminary support for this view. DWT-for-DWT, the least efficient sized tanker in pollution terms was the small vessel in the 10,000-29,000 class. Tankers over 100,000 DWT actually had the best record by this standard, polluting at less than half the rate of the 10,000-29,000 ton ships.^{5/} The large tankers performed only marginally better than the very small (under 9,000 DWT) or medium (30,000-99,000 DWT) vessels, however.

At the extreme, if the 62 new ships planned at the need of 1973 were introduced with no increase in the aggregate deadweight tonnage of the privately-owned tanker fleet under U.S. registry, the oldest 180 vessels now in service,

^{5/} The relative newness of these large ships precludes our ability to predict whether they will be able to maintain their currently favorable pollution record.

TABLE 9
WORLD POLLUTION FROM TANK SHIP CASUALTIES BY DWT CLASS: 1971-1972*

Displacement Class (Thousands of DWT)	Number of Tankers	Number of Pollution Incidents	Volume Spilled (Millions of Gallons)	Average Pollution Incidents Per 100 Ship-Years	Average Volume Spilled Per Pollution Incident (Thousands of Gallons)	Percent of Volume Spilled/Percent of Total Tankers	Percent of Volume Spilled/Percent of Total Deadweight
0.1-9	3,160	85	3.3	1.3	39	0.05	0.82
10-29	1,720	143	40.8	4.2	280	1.15	1.69
30-99	1,491	119	54.8	4.0	460	1.78	0.93
100+	412	29	40.2	3.5	1,400	4.80	0.77
Overall	6,783	376	139.7	2.8	370	Not Applicable	Not Applicable

* Condensed from: *An Analysis of Oil Outflows Due to Tanker Accidents, 1971-1972*, Report No. CG-D-81-74, prepared for USCG Office of Research and Development, November 1973.

most of which fall in the offensive 10,000-29,000 DWT class, could be retired. Such a shift in the composition of the world tanker fleet could theoretically reduce the total annual volume of pollution by roughly 500,000 gallons. This is less than one percent of the average volume of pollution discharged in world-wide tanker accidents during 1971 and 1972, however, and a comparable percentage reduction in the U.S. experience would amount to only 20,000-30,000 gallons a year.

Of course, the actual introduction schedule for new U.S. tankers will not confirm precisely to either of the alternatives (one-for-one replacement of the oldest existing vessels, and replacement of oldest existing vessels with no change in aggregate DWT) postulated here. Nonetheless, examining these extreme cases (the first of which would have the maximum impact in creating additional pollution, the second the minimum) can be useful in projecting the direction of trend in pollution from vessel casualties, if not its extent. On balance, the prognosis favors an even more significant role for vessel casualties in contributing to pollution volume over at least the next several years than was the case during the 1971-1973 study period.

VI. TRANSPORTATION-RELATED FACILITIES

In Section III, it was shown that of each 100 gallons of pollution volume recorded in incidents where both the source and the cause were identified, vessels produced 43, transportation-related facilities produced 16, and non-transportation-related facilities outside Department of Transportation's regulatory jurisdiction produced another 16.^{1/} Coast Guard research has quite properly focused on vessels as the primary source of water pollution.

However, the volume produced by transportation-related facilities (defined in Appendix B), although clearly of secondary importance, has not been trivial. In this section, pollution experience with transportation-related facilities is compared to that with vessels in an effort to identify any similarities or differences in the analytic properties of the two problem areas and to determine the most promising methodological approach to developing effective policies for curtailing pollution from facilities. Particular attention is directed toward the applicability to facilities spills of the ORI spill risk model developed in an earlier report that focused on collisions between moving vessels.^{2/}

^{1/} The final 25 gallons arose from incidents caused by natural phenomena. Such incidents, which had by far the most severe effect on non-transportation facilities, have been considered essentially as non-preventable for the short term throughout this study.

^{2/} Spill Risk Analysis Program Phase II Methodology Development and Demonstration, Final Report Part I, Report No. CG-D-15-75, AD 785 026, August 1974.

COMPARISON WITH VESSEL SPILLS

In contrast to vessels, the most important causes of pollution from transportation facilities are associated with material failures and the breakdown of equipment components. During 1971-1973, such failures were cited in 72 percent of the preventable pollution incidents at transportation facilities, and produced 85 percent of the preventable volume of pollution that was attributed to these facilities. As shown in Table 10, failures of material, structure or equipment figured twice as strongly as a cause of pollution incidents, and played a five times greater role in producing pollution volume, from transportation facilities than from vessels. Collisions, fires, explosions, and other casualty incidents, on the other hand, were cited as the cause of proportionately fewer incidents at transportation facilities than aboard vessels, and were of only minor importance in contributing to pollution volume (less than eight percent compared to 68 percent of the volume from vessels).

A second important distinction between the pollution records of transportation facilities and vessels regards the severity of the pollution produced when an incident does occur. Compared to an average spill of 29,600 gallons for the most important cause of pollution from vessels (i.e., casualty), spills from the most important cause of pollution at marine transportation facilities—(i.e., material, structural or equipment failure) average only 4,400 gallons.

Greatly influencing these averages is the higher probability that an incident involving a vessel will produce a very large (in excess of 100,000 gallons) spill. Surprisingly, incidents involving vessels are also more likely to produce very small spills (less than 100 gallons). These facts are depicted graphically in Figure 8, which compares the frequency distribution of pollution incidents for vessels and transportation facilities according to the volume of pollution released.^{3/}

The figure shows that, given that a pollution incident has occurred, it is more likely to result in a spill of less than 200 gallons or more than 60,000 gallons if it involves a vessel. If it involves a transportation facility, it is more likely to fall between these limits. One plausible explanation for the "double intersection" of the two curves may lie with the reporting system. If the attention of Coast Guard operating personnel is oriented toward vessels, as this study confirms it ought to be, then a relatively larger proportion of the very small spills which are occurring may be being detected and recorded from this source than from transportation facilities which are less closely monitored.

The greater potential of vessels over transportation facilities for producing very large, even catastrophic, spills becomes more clear through the use

^{3/} The very large variance in each of the distributions requires the use of log scales. These scales distort the proportionality from cycle-to-cycle of the shaded areas.

TABLE 10
DISTRIBUTIONS BY GENERAL CAUSE ^{1/}
VESSELS VERSUS TRANSPORTATION-RELATED FACILITIES, 1971-1973

Cause Source		Casualty	Material, Structural or Equipment Failure	Direct Personnel Error	Deliberate Discharge	Total
Incidents: Vessels Transportation-related facilities		10.1	34.8	41.7	13.4	100.0 ^{2/}
		6.3	72.2	18.1	3.4	100.0 ^{3/}
Volume: Vessels Transportation-related facilities		68.4	15.2	7.1	9.3	100.0 ^{2/}
		7.7	84.8	6.6	0.9	100.0 ^{3/}
^{1/} Excludes natural phenomena. ^{2/} Of 6,503 incidents reported, 5,585 recorded 19,100,000 gallons of pollutants spilled. ^{3/} Of 4,053 incidents reported, 3,651 recorded 6,920,000 gallons of pollutants spilled.						

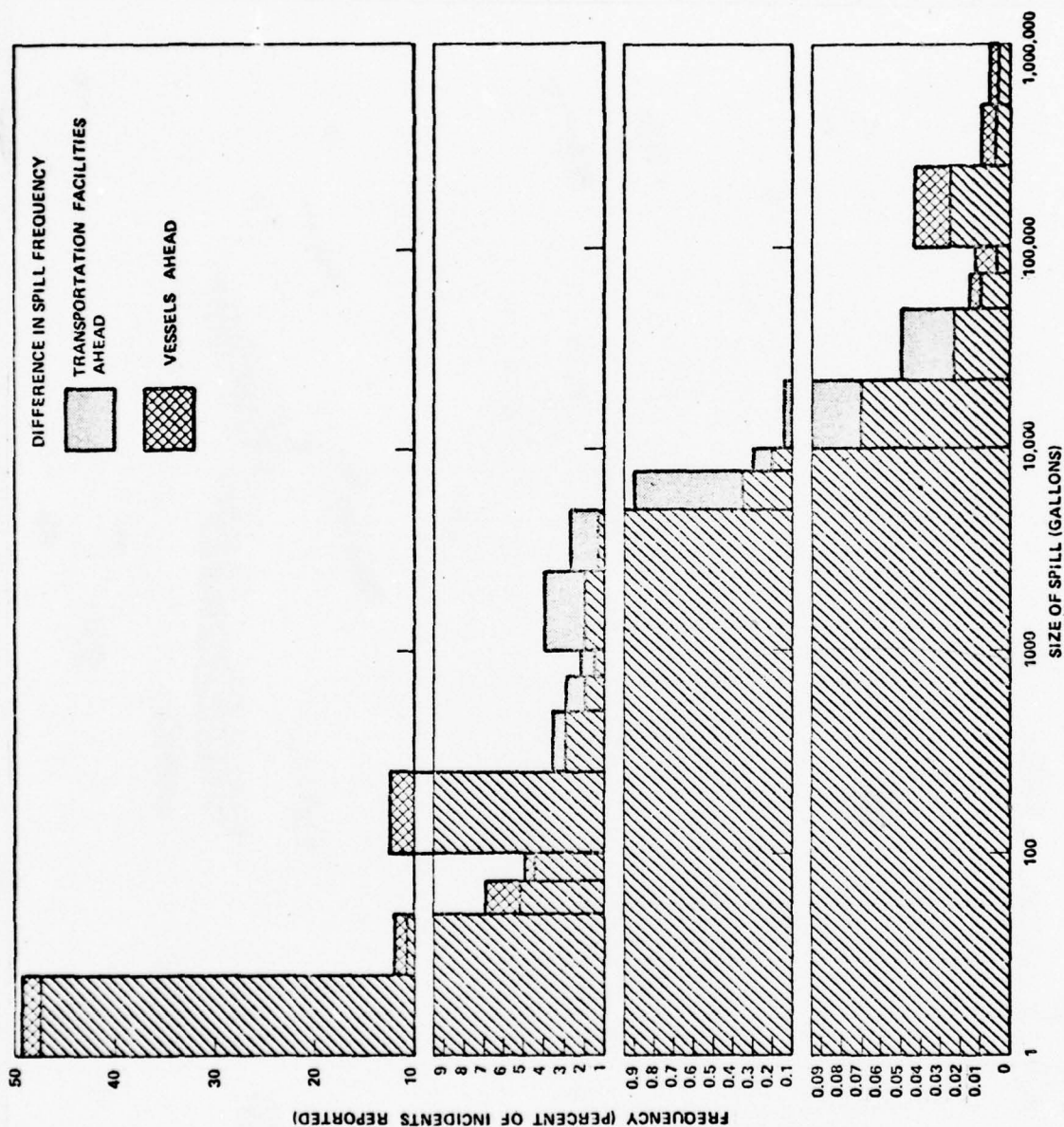


FIGURE 8. FREQUENCY DISTRIBUTIONS OF INCIDENTS BY VOLUME SPILLED, 1971-1973: VESSELS VS TRANSPORTATION FACILITIES *

*Note: Areas are not comparable between cycles.

of cumulative probability functions. Figure 9 plots the same data encompassed in Figure 8 after a cumulative "one minus" transformation has been carried out. The figure shows that incidents involving vessels are almost twice as likely to produce spills above 100,000 gallons as are incidents involving transportation facilities. ^{4/}

ALLOCATING PREVENTIVE RESOURCES

Given these differences in the pollution probability functions for vessels and transportation-related facilities, what, if any, are the implications for Coast Guard management? ^{5/} Although no explicit quantitative answer as to the optimum allocation of Coast Guard preventive resources among alternative sources and causes of pollution is possible without detailed information on the cost side of the problem, it is possible to demonstrate a general approach to the solution utilizing the information that is available concerning the severity of incidents and treating the still unquantified facets of the problem by assumption.

For illustrative purposes, let us suppose that Coast Guard policy-makers set a goal of reducing pollution volume from preventable causes affecting sources within the Coast Guard's jurisdiction (as reported in the PIRS) by 10 percent, or roughly 710,000 gallons, annually. Based on what is already known about the distribution of spills by general source and cause, this goal could be totally achieved by preventing about 24 vessel collisions each year. Alternatively, preventive efforts could be focused entirely on reducing the number of material, structural or equipment failures at onshore marine transportation facilities, in which case measures would have to be taken to prevent about 260 such incidents each year. A third alternative would be to devote some preventive effort to both vessel collisions and material, structural or equipment failures at transportation-related facilities. Which course is preferred?

To answer this question, knowledge of the functional relationship between the costs of preventive efforts and the benefits to be expected in reducing the incidence of pollution events is required. In the absence of information to the contrary, this relationship might be expected to take the form of output (measured in proportionate reductions in the number of pollution incidents) decreasing at an increasing rate as additional increments of input (preventive resources) are provided. Such a relationship is plotted in Figure 10. Solely to provide specificity to our illustration, it is also assumed that there is some minimum level of effort (equal to cost "c") that is needed to achieve any inroads at all in reducing

^{4/} Figure 7 shows the same kind of relationship for vessels and transportation facilities taken as a whole.

^{5/} Earlier, in the last section of Section IV, guidelines were developed in the form of "payoff factors" to assist Coast Guard operating personnel in identifying those specific source/cause combinations which are likely to offer the most promising opportunities to reduce the overall level of pollution volume.

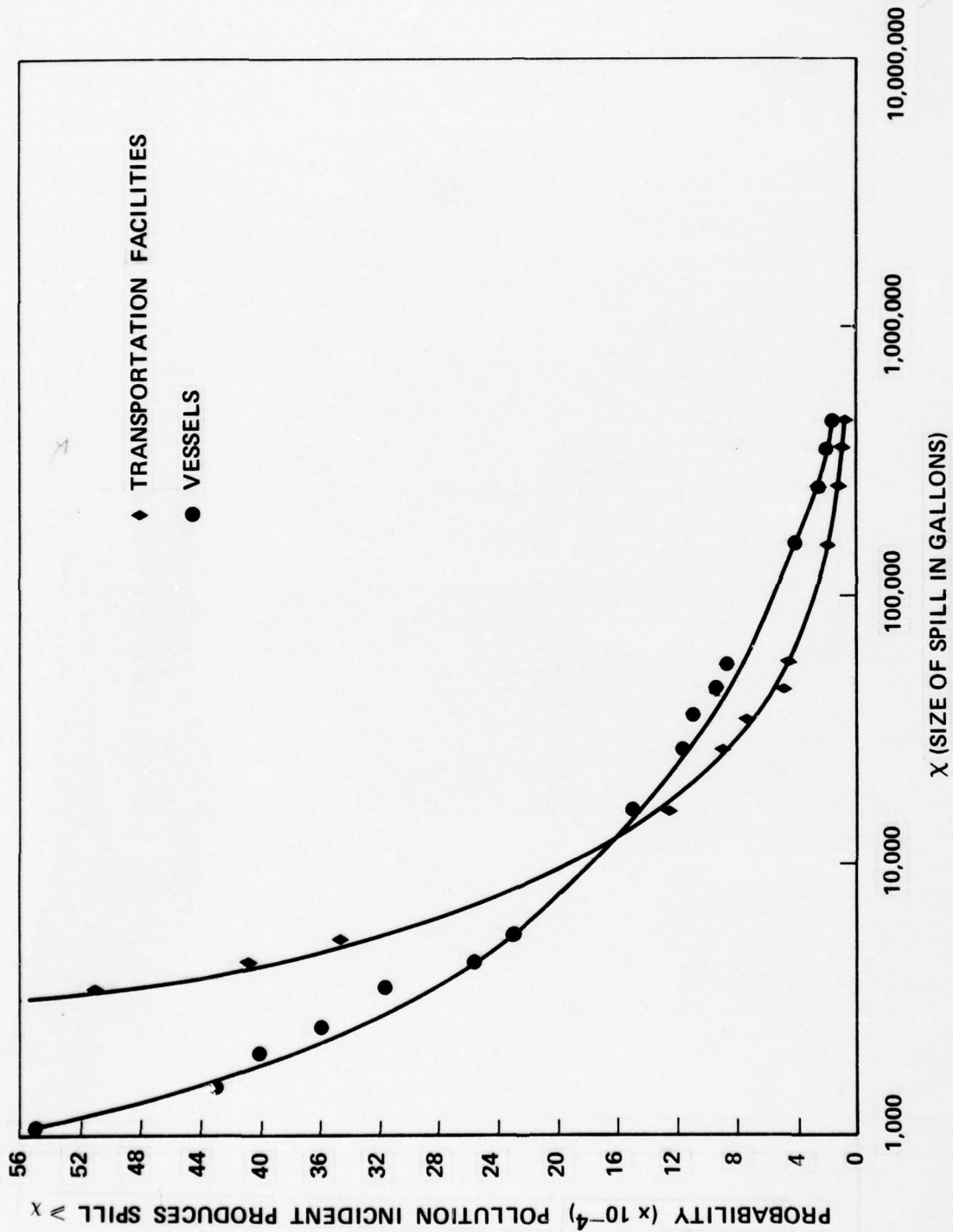


FIGURE 9. CUMULATIVE (ONE MINUS) PROBABILITY FUNCTIONS OF INCIDENTS
BY SIZE OF SPILL: 1971-1973 VESSELS VS
TRANSPORTATION-RELATED FACILITIES

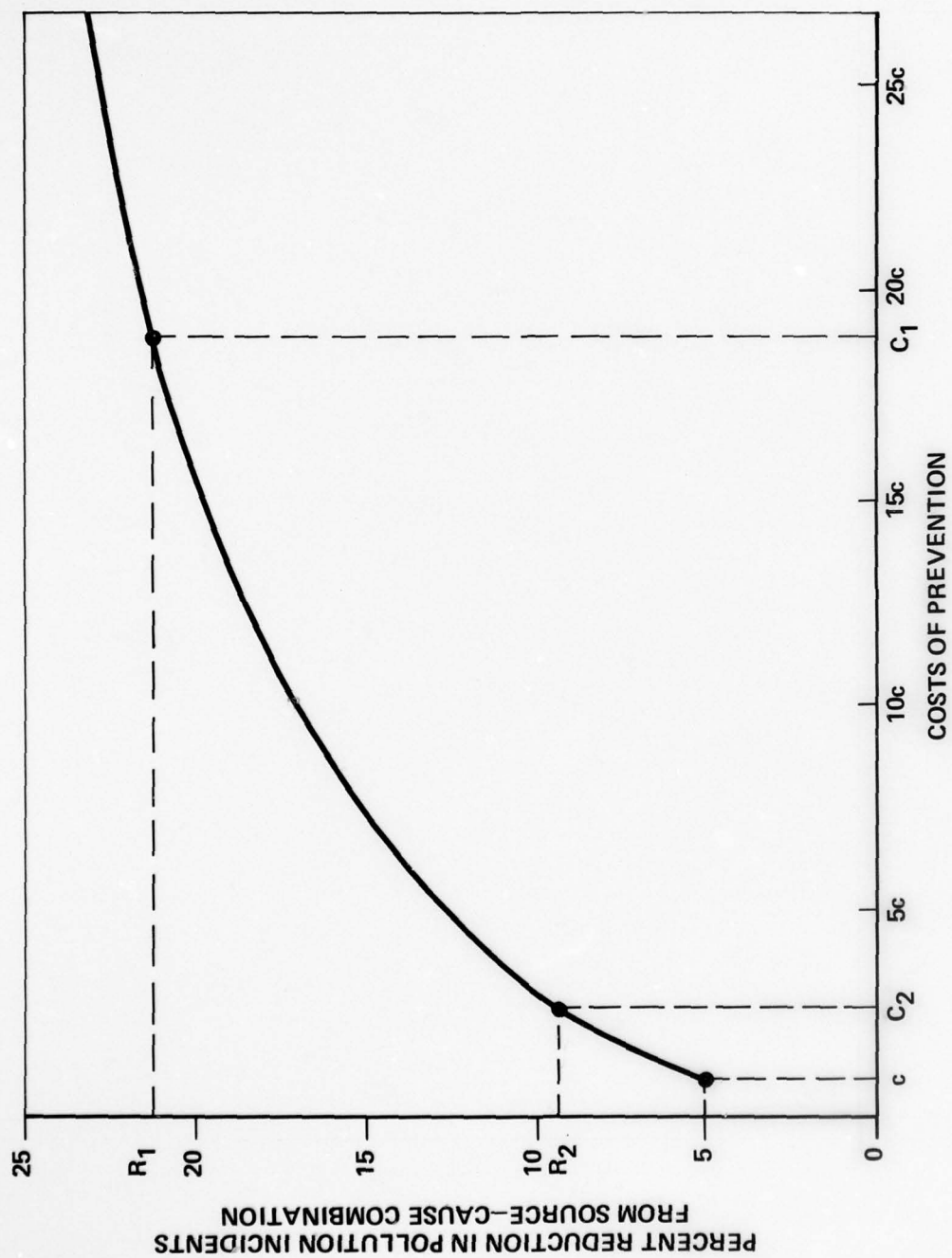


FIGURE 10. ILLUSTRATIVE COST-BENEFIT RELATIONSHIP

pollution, that this "threshold" effort would achieve a five percent reduction in the number of pollution incidents from a given source/cause combination, and that from this point the costs double for each successive five percent incremental reductions in incidence.

If it is further assumed that the cost-benefit relationship shown in Figure 10 applies equally to both vessel collisions and material, structural or equipment failures at transportation-related facilities, then the trade-offs in the reduction in pollution incidence between these source/cause combinations for any overall level of preventive effort may be represented by an infinite family of isocost (constant input)^{6/} curves which take the form of the concentric circles depicted in Figure 11.

The 24 vessel collisions which would have to be prevented annually to meet the illustrative goal of a 10 percent reduction in overall pollution volume with no assistance from reductions elsewhere represents only about 27 percent of the annual average of such incidents during 1971-1973. If, however, the Coast Guard concentrated exclusively on preventing material, structural or equipment failures at onshore marine transportation facilities, the 260 incidents it would have to negate translates to a better than 90 percent reduction. These alternatives are represented by the diagonal line descending to the right in Figure 11. Reference to Figure 10 shows that a strategy of concentrating entirely on vessel collisions to achieve the overall goal would, under the specific assumptions of our example, cost 35 times as much as the basic threshold program. Achieving the required 92 percent reduction in the incidence of material, structural or equipment failures at transportation facilities would cost much, much more (well off the scale of Figure 10). Under these conditions should the Coast Guard focus entirely on preventing vessel casualties to achieve its overall goal? In this example, the answer is: almost, but not quite.

The optimum allocation of resources between the two source/cause combinations is that which yields the desired goal at the least total cost. Accepting a few percentage points smaller reduction in vessel casualties would free some resources that, in this example, could be more productively employed in preventing material, structural or equipment failures at transportation-related facilities. The solution to the problem is arrived at graphically by finding that isocost curve which is tangential to the diagonal representing alternative means for achieving the desired reduction in overall pollution volume. This occurs at point P in Figure 11, which corresponds to a reduction of R_1 (about 21 percent), in the incidence of vessel casualties and R_2 (about 9 percent), in the incidence of material, structural or equipment failures at transportation-related facilities. Again referring to Figure 10, the costs of achieving these reductions are C_1 (equal to 19.0C) and C_2 (equal to 2.5C) respectively: a total cost of 21.5C compared to the 35C it would cost to achieve the same reduction in overall volume if all additional preventive resources were devoted to preventing vessel collisions and none to material, structural or equipment failures at transportation facilities.

^{6/} The assumption that costs of strategies for preventing pollution from vessel and facilities is theoretical. Individual corrective strategies should be evaluated on their own merits with cost as an important parameter.

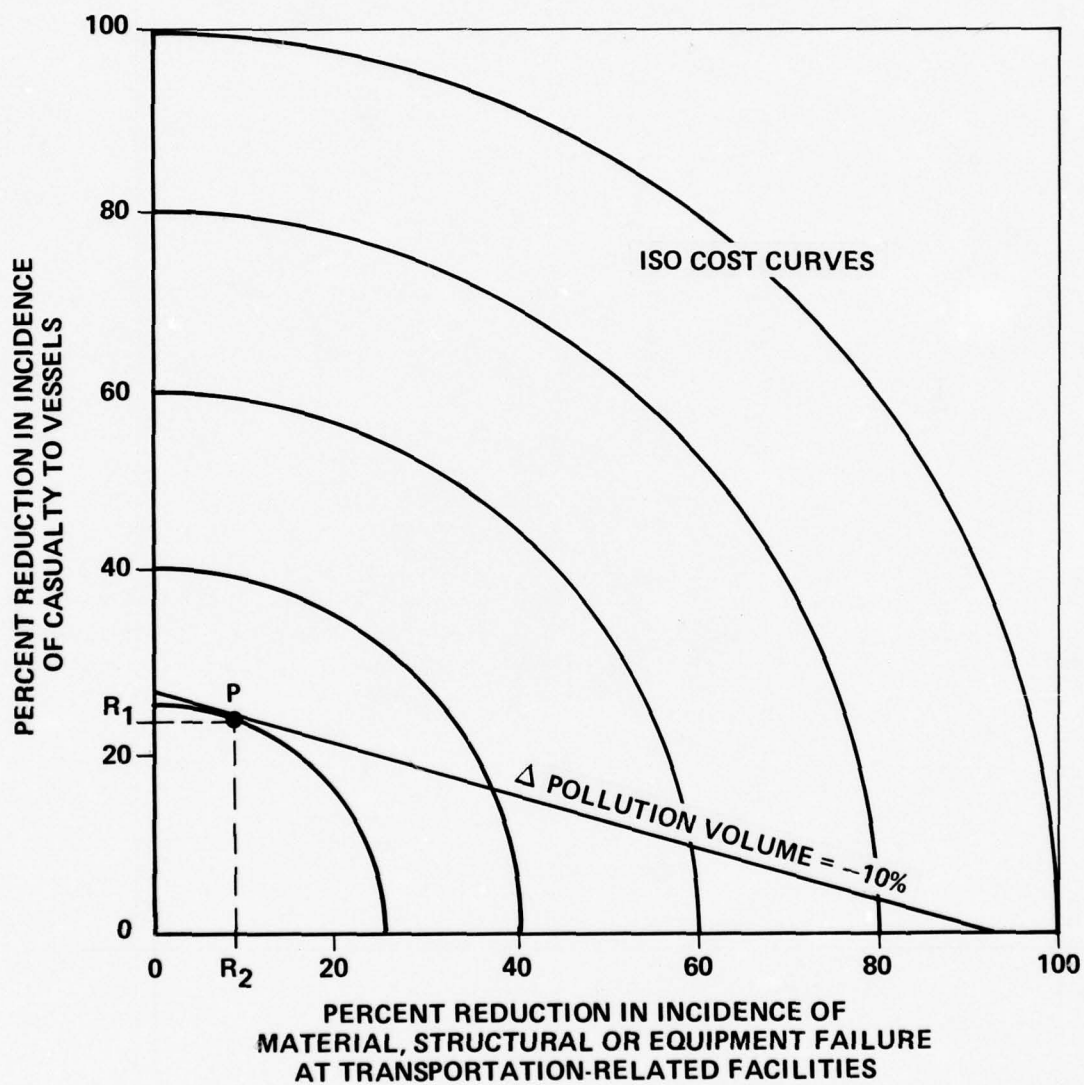


FIGURE 11. GRAPHICAL SOLUTION TO THE ILLUSTRATIVE RESOURCE ALLOCATION PROBLEM

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VII. APPLICATIONS FOR SPILL-RISK ANALYSIS METHODS

Two questions that were raised in earlier work^{1/} in Coast Guard risk analysis research were:

1. Does the spill experience, in both the total number of incidents and total volume, from onshore and offshore facilities exceed that originating from vessels as was indicated by a superficial initial examination?
2. Will risk analysis techniques developed for vessel casualties apply to the facilities spill problem?

The analyses reported in the preceding chapters address the reply to the first question in detail. We now turn our attention to the problem of the second question.

SPILL-RISK ANALYSIS METHODS

The research that had been completed prior to this report addressed the spill-risk analysis problem in both general and specific terms. The general approach modelled the number of spills expected to occur within a region of interest during some period of time. This process is very similar to what is generally referred to in military operations research as the development of an "evaluative" model. These evaluative models are not only valuable as measures of system effectiveness, but they also help to structure an overview of the problem in such a way that a logical set of subanalyses can be initiated. The specific methods, or tools, which were developed for the Coast Guard risk management program relative to vessel casualties were the scenario model and the quasi-experimental methods which have been extended and are presented in the previous sections of this report.

^{1/} Report No. CG-D-15-75 op. cit.

GENERAL SPILL RISK ANALYSIS METHODS

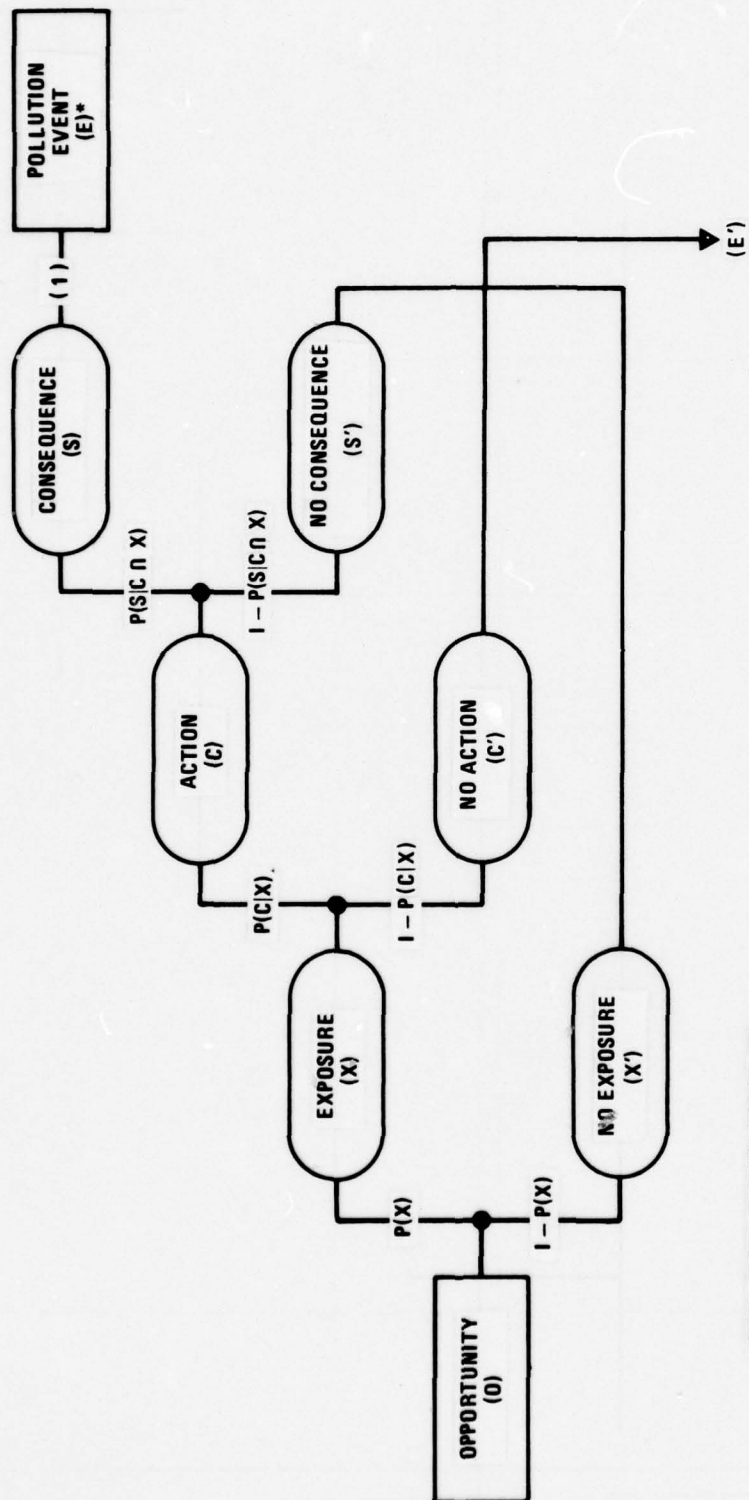
The development of an evaluative model for facilities analysis is very similar to that followed in the case of the vessel casualty ~~spillage~~ equation. Reduced to general fundamentals, the occurrence of a pollution event may, regardless of its specific cause, be conceptualized as the culmination of a sequence of necessary subevents, each of which occurs with a certain probability. Using this conceptual framework, illustrated by the diagram in Figure 12, the problem of reducing pollution volume becomes one of reducing the probability that a pollution event takes place by interrupting, at any point, the essential chain of subevents.

As shown in the diagram, three theoretical opportunities exist for avoiding a pollution event; that is, there are three vulnerable links in the chain of subevents (opportunity-exposure; exposure-action, or cause as defined in the PIRS; and action-consequence), any one of which may be broken to successfully avert the undesired final product of a pollution event. In the case of the principal cause of pollution from transportation-related facilities, the failure of material, structural or equipment components, the first link in the chain of subevents, opportunity-exposure, is not operative. If one of these components is in service, it is also exposed to this type of action.^{2/} Efforts to reduce the incidence of pollution from this source/cause combination are, therefore, presented only two points at which to disrupt the sequence of subevents that precedes the discharge of pollution: the exposure-action and the action-consequence junctures shown in Figure 12.

Unlike the vessel casualty problem, where the challenge is to avoid a small number of rare occurrences which individually tend to produce large negative payoffs (volumes of pollution), the problem of reducing pollution volume from material failures at transportation related facilities is one of avoiding a much larger number of comparatively common occurrences, the individual consequences of which are generally much less severe.

The problem of breaking the exposure-action link in the chain of subevents that leads to a discharge of pollutants from this source/cause combination is a complex one. Generally, the basic problem is premature equipment failure which may be caused by faults in design, procurement, operation, and maintenance. We will illustrate this consideration by discussing the preventive maintenance problem. Equipment replacement theory, which encompasses maintenance issues, centers on economic considerations. Geometry, the foundation of all intercept problems (including the ORI maneuvering analysis model) is of no use in analyzing material failures.

^{2/} In the case of vessel collisions, it is feasible to attack the opportunity-exposure link. Given that there is an opportunity for a pollution event to occur (which, in this case, might be defined as two vessels within a physical proximity that would allow interception within 24 hours), exposure (entering the "collision region") could be prevented by a variety of scheduling measures (adjusting sailing times, stacking, advance vectoring instructions, etc.). If exposure can be prevented in such a way, the probability of the action (collision) taking place is reduced to zero.



$$*P(E) = P(X) \cdot P(C|X) \cdot P(S|C \text{ and } X)$$

FIGURE 12. GENERAL SEQUENCE PRECEDING A POLLUTION EVENT

Typically, failures of material components of identical design that have received identical maintenance will be randomly distributed as illustrated in Figure 13. For the purpose of clarity in constructing the figure, it was assumed that the component in question (which may be a valve, pump, hose, pipe, storage tank or whatever) has an expected service life under "ordinary" maintenance and utilization schedules that is equal to its mean time to failure (that is, the length of time in which half of the like components would be expected to fail), and that this mean failure time lies exactly four standard deviations of the probability of failure function from the date the component is introduced into service. To further simplify the illustration, it is also assumed that the component in question is not economically repairable (as is the case, for example, with an ordinary light bulb) once it has failed.^{3/}

Every business enterprise must constantly grapple with the issue of when to replace a particular capital asset. If the component is replaced before it has failed, the owners incur only the costs directly associated with procuring and installing the new component, plus whatever losses in production ensue from installation downtime. If the enterprise waits until the component at issue has failed before replacing it, a number of additional costs will also be incurred. Should a pollution incident result, the full costs of the component failure will not only include the value of the product that is released and the premium that is usually associated with unscheduled downtime, but also, in many cases, the costs of cleaning up the spill. In addition, the company runs a risk of incurring a fine or the extra expenditure to implement any corrective measures that might be imposed by a regulatory agency. Finally, there would be the possibility of adverse publicity, the implicit costs of which, though not readily quantifiable, cannot always be ignored. The kinds of additional costs a business entity would associate with a component failure may be summarized as follows:

- Direct Replacement Cost
 - . Procurement
 - . Installation
 - . Scheduled downtime.
- Additional Costs of Component Failure
 - . Inventory loss
 - . Premium for unscheduled downtime
 - . Clean-up*
 - . Imposed corrective measures*
 - . Fine*
 - . Adverse publicity.*

* Probability less than one.

^{3/}

Altering these assumptions adds complexity to the analysis, but in no way affects the principles being demonstrated.

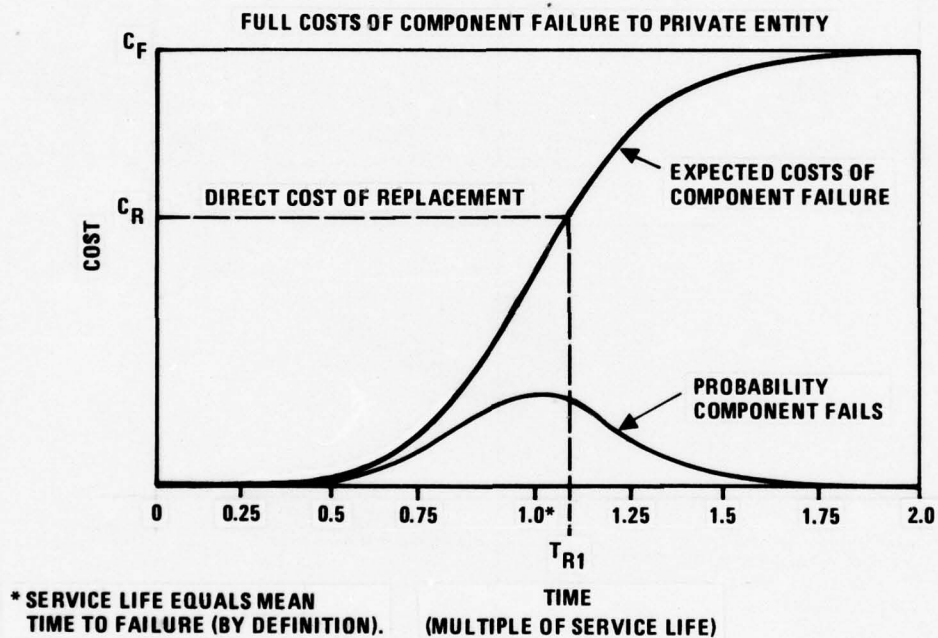


FIGURE 13. TIME TO COMPONENT REPLACEMENT:
ORDINARY MAINTENANCE

Obviously, any profit-oriented entity has some incentive to avoid the full costs of component failure. It is equally clear that the same entity also has an incentive for avoiding the costs of premature replacement of a component that is still capable of reliable service. A compromise must be struck. From the point of view of the private entity, the theoretically optimum time at which to replace the component in question is after that period of service which minimizes the entity's average cost of owning and operating the component. The way in which this optimum time to replace the component may be determined is demonstrated in Figure 13. Average cost of ownership is at a minimum after a period of service wherein the direct costs of replacement just equal the full costs the entity perceives it would incur if the component fails multiplied by the probability the component will have failed by that time.^{4/}

This point is indicated in Figure 13 at the intersection of the horizontal line representing direct replacement costs (C_R) with the expected costs of component failure curve (the product of the cumulative probability of failure and the full costs that the owner perceives he would incur as a consequence of that failure, C_F). In the example cited, direct replacement cost is equal to two-thirds the full costs of component failure to the private entity. The component in question, and all others like it, would be replaced after a period of service equal to T_{R1} , or about 1.1. times the service life.^{5/} Under this replacement scheme, while optimum in terms of minimizing the average costs incurred by the entity that owns the component, more than half the components in question would fail prior to replacement. And some of these failures would produce pollution events.

In addition to the question of when to replace a structure, machine or part, the business entity must also confront the closely related question of how much to spend to maintain a component. If, in place of ordinary maintenance at some constant rate as was assumed in Figure 13, the owner pursues a more intensive maintenance schedule, the effect of his extra maintenance would tend to compress the probability of failure function, and shift it to the right in the manner indicated by Figure 14. Given no change in either the direct cost of component replacement or the full costs of component failure, the extended mean time to failure brought about by the extra maintenance might tempt the owning entity to extend the replacement time for the component in question to T_{R2} . The entity must, however, take into account the additional costs it is incurring to support the intensified maintenance schedule. The optimum replacement time under the assumption of intensified maintenance would occur at the earlier time, T_{R3} , found by locating the intersection of the net cost of replacement (C_N) and the expected full cost of component failure curve.

4/

Figure 13 assumes ordinary maintenance at a constant rate and, therefore, constant annual cost. Figure 14 assumes increasing maintenance costs per unit time over the service life of the component.

5/

Under the assumption that the component is not responsible, C_R must always be less than C_F . A ratio C_F smaller than that assumed in the example would lead to earlier replacement; a ratio larger than assumed would delay replacement.

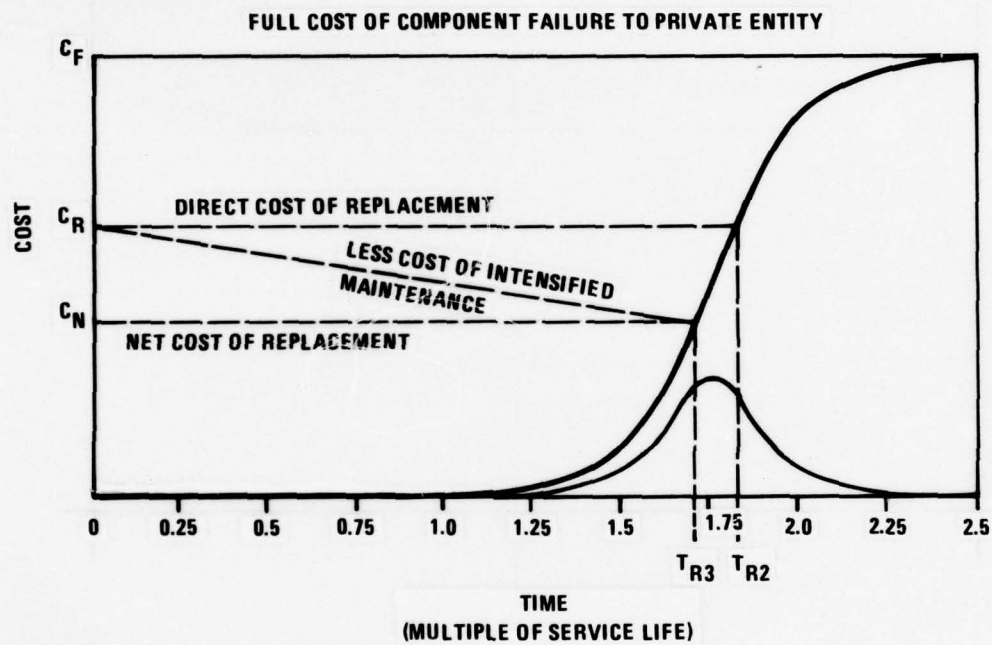


FIGURE 14. TIME TO COMPONENT REPLACEMENT:
INTENSIFIED MAINTENANCE

Although the private entity retains the components that represent a potential pollution hazard in service longer under the intensified maintenance example than under the ordinary maintenance example, the likelihood that one will fail prior to its replacement has been reduced. With fewer components failing, proportionately fewer pollution events produced by this source/cause combination would be expected to occur, and a reduction in pollution volume would be achieved.

If the full costs associated with a pollution event accrued to the profit entity that owned the component whose failure was responsible for the event, no regulatory actions would be needed to encourage optimization of maintenance and replacement policies. The entity would have all of the incentives it needed to pursue such policies of its own accord, constrained only by the pragmatic realities of imperfect knowledge as to the values of the relationships depicted in Figures 13 and 14. In this environment, the principal role of governmental agencies might well be limited to actions designed to improve the quality of the information upon which the decision of private managers would be based (by requiring, for example, manufacturers of the components in question to provide detailed information on their performance and failure function under varying conditions).

In real life, the cost a profit entity is likely to associate with a component failure that leads to a pollution event does not reflect the full cost of that event in a broad social context. The costs of remedial action, either to clean-up or to contain a spill, are partially borne by the general public through the budgets of various regulatory agencies. The administrative overhead of these agencies is another public cost of pollution. But most important, there are the costs not readily expressed in economic terms because the resources affected are neither transferred through the marketplace nor consumed in the usual sense by individual persons or organizations.

Contemporary society has clearly placed a value on certain qualities of the physical environment. Any event which tends to depreciate any one of these qualities, as does the discharge of pollutants into the nation's waterways, therefore exacts a very real cost, notwithstanding the difficulties inherent in arriving at an exact economic dollars-and-cents expression for it.

Returning to an "ordinary" maintenance assumption, Figure 15 shows how the difference between the costs a private entity associates with the failure of a component and the full social costs associated with the pollution event that failure could produce tends to lead the private entity to delay the replacement of the component beyond the time that is optimum from a broad social perspective. ^{6/}

^{6/} For convenience, Figures 15 and 16, and the comments pertaining to them, assume that every component failure leads to a pollution event (i.e., $P(S | C \cap X) = 1$. (See Figure 12)).

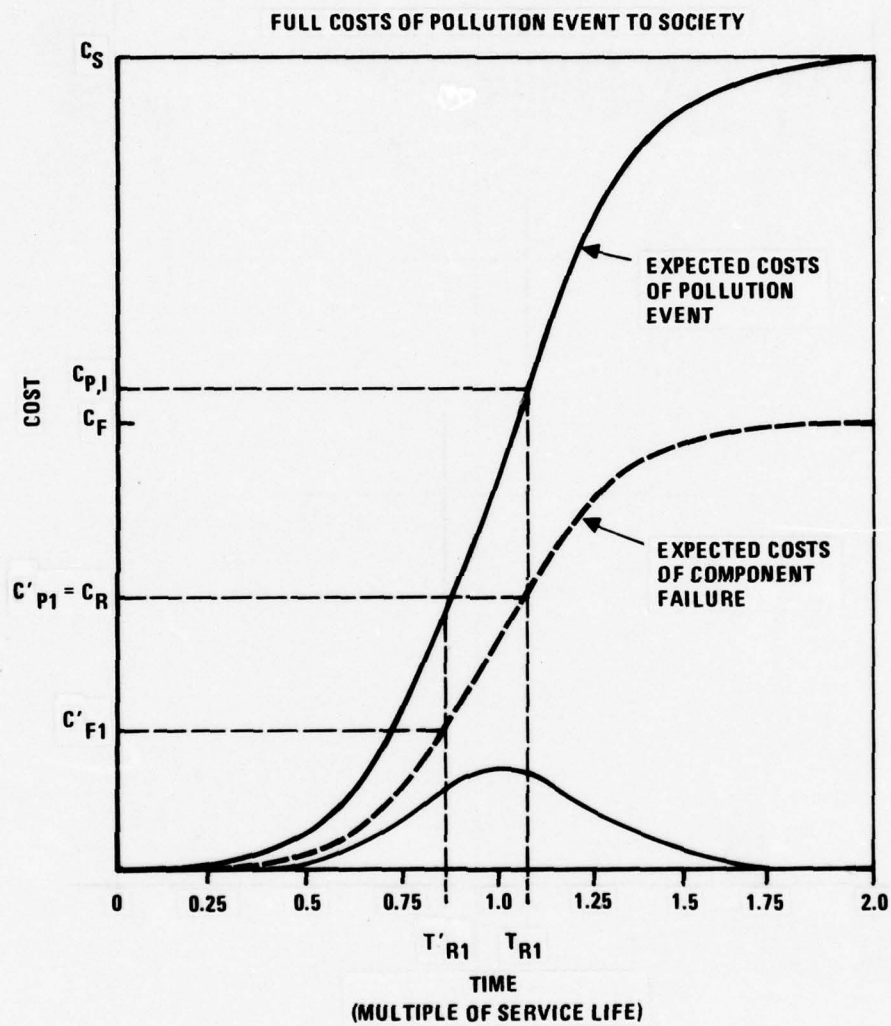


FIGURE 15. TIME TO COMPONENT REPLACEMENT CONSIDERING
FULL SOCIAL COSTS OF POLLUTION EVENT;
ORDINARY MAINTENANCE

The private entity that minimizes its average cost of ownership by replacing a component after T_{R1} years of service leaves a residual cost in the form of the pollution produced by those components that fail before they are replaced (equal to $C_{p1} - C_R$ in Figure 15) to be borne by the general public. ^{2/} Considering the full costs of a pollution event (C_S) rather than only that fraction that accrues to the private entity (C_F) leads to an earlier optimum replacement time, T'_{R1} .

Since the private entity has no motivation to replace the component in question before T_{R1} years of service (if it replaces the component at the optimum time in terms of full social costs, its average costs would be increased by an amount equal to $(C_R \div T'_{R1}) - (C_R \div T_{R1})$, or about 20 percent in the example under discussion), some incentive must be provided. Any punitive measures which served to narrow the gap between the full social costs of a pollution event and the private entity's perception of the costs of component failure would serve this purpose. Alternatively, since compelling the private entity to replace the component in question earlier would have the effect of shifting a portion of the full cost burden that would otherwise accrue to the public onto the private entity (at T'_{R1} , $C'_{p1} = C_R$ which is of course, borne entirely by the entity) positive incentives in the form of subsidies to encourage earlier replacement might be considered to partially compensate the entity for the difference between C_R and C'_{p1} , its expected cost at time T_{R1} . At the extreme, a full subsidy in this amount could be provided at less cost to the public sector than would be incurred if the entity waited until T_{R1} to replace the component in question.

If the owner follows the same policy of intensified maintenance and achieves the same shift in the probability of component failure function as was illustrated in Figure 14, the relationship between society's full cost expectations and the fraction of this amount that the owning entity would expect to incur would take the form depicted in Figure 16. All of the basic arguments developed for the ordinary maintenance case also apply under an intensified maintenance schedule. Comparing the cost relationships depicted in Figure 16 with the comparable relationships depicted for the ordinary maintenance case in Figure 15 shows how an intensified schedule of preventive maintenance can reduce both the private cost of owning a structural or equipmental component, and the public costs associated with the component's potential for failure and the risk of pollution such failure entails.

Under the postulated schedule of intensified maintenance, the point in time at which it would become more expensive for the private entity to retain the hypothetical component in service than it would be to replace it is postponed to T_{R3} , as shown in Figure 16. Since the entity's average cost of

^{2/} This is not to imply any malice whatever in the motives of the private entity, which is in fact acting precisely as it should given its less than comprehensive cost perspective.

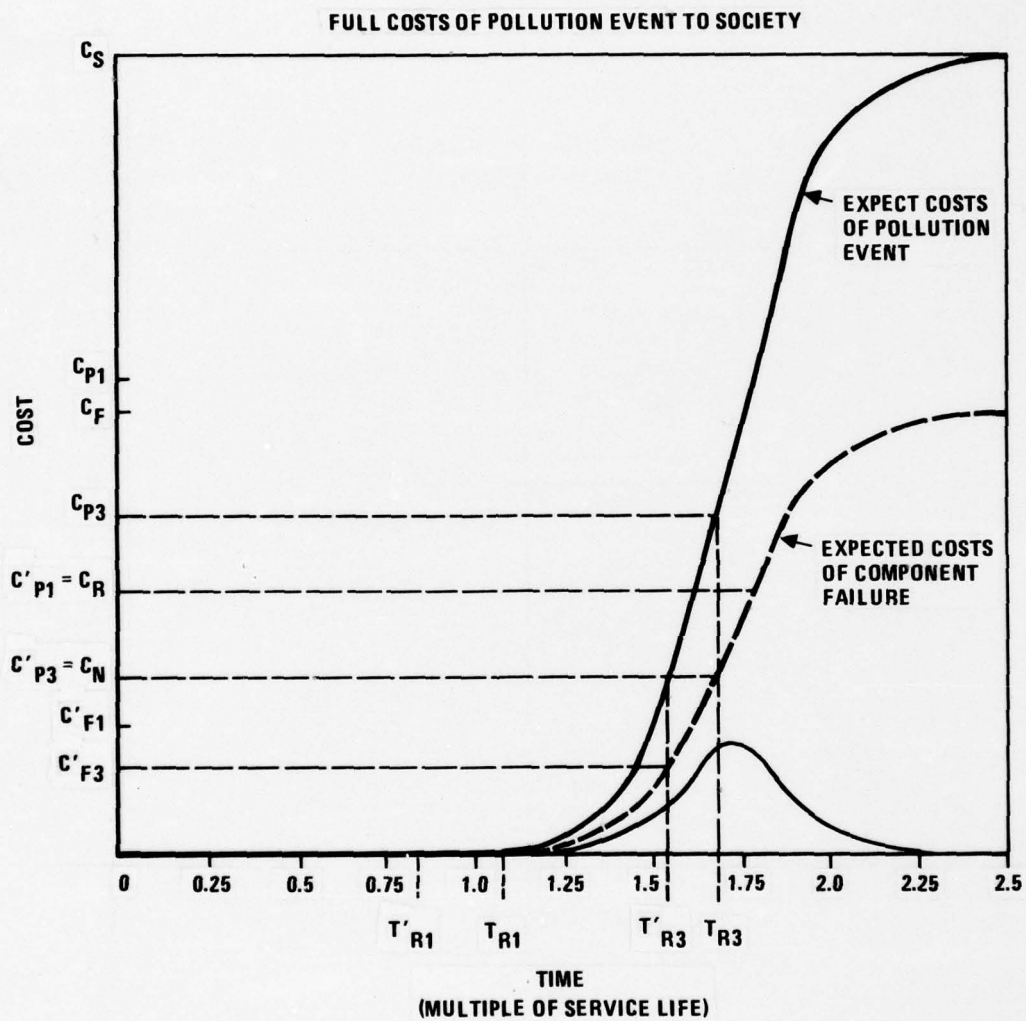


FIGURE 16. TIME TO COMPONENT REPLACEMENT CONSIDERING
FULL SOCIAL COSTS OF POLLUTION EVENT:
INTENSIFIED MAINTENANCE

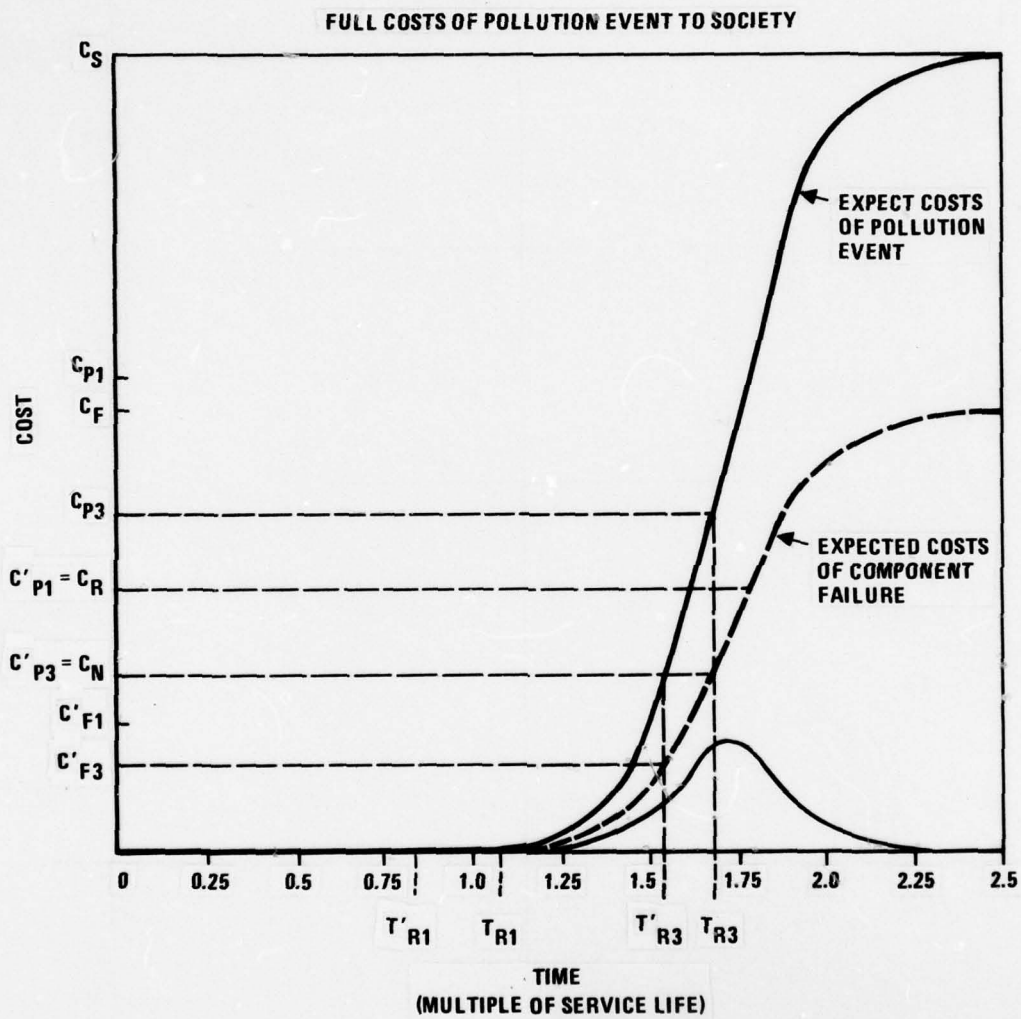


FIGURE 16. TIME TO COMPONENT REPLACEMENT CONSIDERING
FULL SOCIAL COSTS OF POLLUTION EVENT:
INTENSIFIED MAINTENANCE

ownership would be substantially less than under the postulated ordinary maintenance schedule, ^{8/} it would have a definite economic incentive to pursue the intensified maintenance schedule. Moreover, the public burden in terms of the expected costs associated with pollution event would be markedly lower (by an amount equal to $C_{p1} - C_{p2}$ in Figure 16).

Although intensive preventive maintenance has reduced costs for both the private entity and the public in this example, the replacement time (T_{R3}) chosen by the entity is no more the optimum from a broader social perspective than it was under the ordinary maintenance case. Overall cost to society, both private and public, would be minimized by replacing the component in question after a period of service equal to T'_{R3} , at which time the expected public cost burden is only $C'_{p3} - C'_{F3}$. As with the ordinary maintenance example, some incentive, either in the form of penalties to lift the private entity's perceived cost of component failure curve, subsidies to lower the entity's net cost of replacement, or simply regulations stipulating when a component must be replaced, remains necessary to promote equipment and structural replacement policies that serve to minimize total social costs, not merely that fraction with which a private economic entity would ordinarily identify.

Complementing the action discussed above to interrupt the exposure-action link in the sequence of subevents that precedes a pollution event, efforts could also be undertaken to reduce the likelihood that pollutants would in fact be discharged when a material, structural or equipmental component fails (i.e., reduce $P(S|C \cap X)$ as shown in Figure 12). Measures aimed at interrupting this, the action-consequence link, could take a wide variety of forms and include many different kinds of specific safety devices, from automatic shut-off valves for transfer operations to catch basins or drainage systems to contain and channel the effluent from a ruptured storage tank. It should be recognized, however, that to the extent the addition of such devices increases the direct replacement costs of tanks, hoses, pumps, or any other component, it also extends the time a private entity would retain the component in service in order to minimize its costs. Such additions therefore also tend to increase the probability that the component will fail prior to replacement. Hence, analysis of the cost-effectiveness of devices intended to reduce the expected pollution consequences of component failures must address the counterproductive implications of such devices on the exposure-action link, which could be significant if the reliability of the devices is low, or their costs are high relative to the costs of the components they are designed to protect.

^{8/} This need not always be the case. The relationship between additional expenditures for maintenance and the improvements in the probability of component failure function has been exaggerated in Figures 14 and 16 in order to better illustrate the concept.

SPECIFIC SPILL-RISK ANALYSIS METHODS

As noted in an earlier section of this chapter, the specific methodologies developed for the analysis of vessel casualty spill problems are the scenario model and the quasi-experimental method. The scenario model, as a dynamic simulation of vessel collisions, obviously has no direct transferability to the facilities area. This does not mean that a similar model could not be developed to simulate casualties within facilities. Given the wide range of facility types, and an even wider range of equipments subject to failure within the various facilities, the feasibility of developing a simulation having the general utility of the vessel scenario model is questionable. The transferability of the research in the quasi-experimental method (QEM) is another matter.

The analysis in the previous chapters is almost exclusively based on the PIRS data base. While the PIRS provides an excellent foundation for statistical analyses, it is not sufficiently detailed to produce a deep analysis of the contributing factors in the many spill casualty scenarios that arise in the facilities arena. The quasi-experimental methodology developed by ORI for analysis of vessel casualty reports would apply in analyses of pollution incident investigation reports as well and this could provide the depth which is lacking in an analysis of PIRS statistics alone. The quasi-experimental methodology is a semi-quantitative means of removing judgment factors from the study of narrative information. This method is described in detail in a previous ORI report^{9/} and builds on earlier work by Campbell and Stanley.^{10/} Its application to three separate problems now being faced by Coast Guard decision-makers is demonstrated in another section of this report.

A thorough demonstration of the application of the QEM was beyond the scope of this current effort. One factor affecting this outcome was that pollution incident investigation reports are not filed at Coast Guard headquarters as are vessel casualty investigative reports. Toward the end of the period during which the research now being reported was carried out, a small sample set of pollution incident reports was received from various district headquarters. These reports were obtained through the cooperation of the Program Review and Budget Staff of the Office of Marine Environment and Systems (G-WEP-1). The forty one reports reviewed were all from calendar years 1973 and 1974. The content of these reports is very similar to vessel casualty report content.

The application of the QEM to pollution incident investigation would entail the development of pollution event sequence diagrams similar to the collision event diagram previously developed. This would be followed by the

^{9/} Report No. CG-D-15-75 op. cit.

^{10/} Experimental and Quasi-Experimental Designs for Research, Donald T. Campbell and Julian C. Stanley, Rand McNally, 1966.

production of a safety analysis logic tree (SALT) as was done in the vessel casualty case. The final development would be that of a casualty analysis gauge (CAG). Since the development of the CAG is dependent upon the specific problem at hand, and due to a shortage of time and funding, this effort was not undertaken. The review of the pollution incident report sample did indicate that such an effort would be reasonable and practical if the Coast Guard should desire to further investigate the power of the QEM.

APPENDIX A

CLASSIFICATION SYSTEMS USED BY THE POLLUTION INCIDENT REPORTING
SYSTEM (PIRS) TO RECORD SOURCES AND CAUSES

SOURCE/CAUSE CLASSIFICATION SYSTEM IN USE DURING 1971-1972

SRC

Source—Two Digits

Insert the code which best describes the activity in which the source or suspected source of the discharge or near-discharge is normally engaged. The source will not always be the same as the party responsible for causing the discharge or near-discharge. (Example: If a barge cargo tank overflows, the barge should always be considered the source even though personnel error or equipment failure on shore may have caused the incident.) If the source is believed to be one of the six general classes listed below (vessel, marine facility, etc.) but the specific type is not known, enter 00, 10, 20, 30, 40, or 50, as appropriate. A transfer hose should be considered part of the vessel, vehicle, or facility which owns it. Wherever possible identify the source specifically in message text.

MARINE TRAFFIC SYSTEMS

Vessel

- 00 Other vessel (specify in text) or unknown type of vessel
- 01 Passenger, self-propelled
- 02 Dry cargo, self-propelled
- 03 Tanker, self-propelled
- 04 Towboat or tugboat
- 05 Dry cargo barge
- 06 Tank barge
- 07 Fishing
- 08 Recreational
- 09 Combatant

Marine Facility

- 10 Other transportation-related marine facility (specify in text)
- 11 Onshore bulk cargo transfer
- 12 Onshore fueling
- 13 Onshore non-bulk cargo transfer
- 14 Offshore bulk cargo transfer
- 15 Offshore fueling
- 16 Offshore non-bulk cargo transfer

LAND TRANSPORTATION SYSTEM

Vehicles

- 20 Other land vehicle (specify in text) or unknown type of land vehicle
- 21 Rail vehicle liquid bulk
- 22 Rail vehicle dry bulk
- 23 Rail vehicle general cargo
- 24 Rail vehicle transfer
- 25 Highway vehicle liquid bulk
- 26 Highway vehicle dry bulk
- 27 Highway vehicle general cargo
- 28 Highway vehicle passenger

Land Facility

- 30 Other land transportation facility (specify in text) or unknown type of land transportation facility
- 31 Railway cargo transfer
- 32 Railway fueling facility
- 33 Highway cargo transfer
- 34 Highway fueling

PIPELINES

- 40 Other transportation-related pipeline
- 41 Onshore transportation-related pipeline
- 42 Offshore transportation-related pipeline

NON-TRANSPORTATION-RELATED FACILITIES

- 50 Other onshore non-transportation-related facility
- 51 Onshore refinery
- 52 Onshore bulk storage facility (includes tank farms)
- 53 Onshore industrial plant or processing facility
- 54 Onshore oil or gas production facility
- 55 Other offshore non-transportation-related facility
- 56 Offshore production facility

MISCELLANEOUS

- 80 Miscellaneous—other source not covered by any of the categories listed above (specify in text)
 - 99 Unknown type of source
- Example: Refinery SRC.51

CAU

Cause—Two Digits

Select the code which best describes the most important event which caused the spill or near spill.

CASUALTY

- 00 Other casualty (specify in text)
- 01 Collision between source and another vehicle
- 02 Collision between source and fixed object
- 03 Fire
- 04 Explosion
- 05 Grounding
- 06 Capsizing or overturning
- 07 Sinking or foundering
- 08 Well blowout

RUPTURE, LEAK OR STRUCTURAL FAILURE

- 10 Other cargo rupture or leak (specify in text)
- 11 Tank rupture
- 12 Other major vehicle structural failure; not collision
- 13 Other minor vehicle structural failure; not collision
- 14 Storage tank rupture
- 15 Other storage tank leak
- 16 Hose rupture
- 17 Line leak
- 18 Pipe rupture
- 19 Pipe leak
- 20 Weld failure
- 21 Corrosion or rust
- 22 Defective fitting valves or closures
- 23 Loose fitting valves or closures

EQUIPMENT FAILURE

- 30 Other equipment failure (specify in text)
- 31 Valve failure
- 32 Pump failure
- 33 Alarm failure
- 34 Automatic shutdown device failure

PERSONNEL FAILURE

- 40 Other personnel failure (specify in text)
- 41 Tank overflow, inadequate soundings
- 42 Tank overflow, incorrect valve alignment
- 43 Tank overflow, list in trim error
- 44 Tank overflow, failure to shut down when topped off
- 45 Tank overflow, topping off at excessive rate
- 46 Incorrect valve handling
- 47 Flanges not properly secured
- 48 Improper hose connection
- 49 Overpressurization of cargo tank

DELIBERATE DISCHARGES

- 50 Other deliberate discharges (specify in text)
- 51 Pumping bilges
- 52 Pumping ballast
- 53 Disposal of other waste oil
- 54 Discharge under EPA permit
- 55 Discharge under COE permit
- 56 Sabotage
- 57 Vandalism

NATURAL PHENOMENON

- 60 Other natural phenomenon (specify in text)
- 61 Natural seepage thru sea bottom
- 62 Heavy unanticipated rains
- 63 Flooding
- 64 Unanticipated freezing
- 65 Unanticipated heavy winds
- 66 Unanticipated heavy seas
- 67 Unanticipated external heat

UNKNOWN

- 99 Unknown cause

SOURCE/CAUSE CLASSIFICATION SYSTEM IN USE DURING 1973

SOURCE

- a. Enter three digits which best indicate the source or suspected source of the discharge or potential discharge. The source may not always be the same as the party responsible for the discharge or potential discharge. For example, if a barge cargo tank overflows, the barge should be considered the source of the discharge, even though personnel error or equipment failure ashore may have caused the incident. A transfer hose, pipe, or loading arm, etc., should be considered part of the vessel, vehicle, or facility which owns it. Use the following code:

1. Marine Traffic Systems

(a) Vessel:

000	Other vessel or unknown but suspected vessel
010	Tank ship 0-149 gross tons (GT)
011	150-299 GT
012	300-499 GT
013	500-999 GT
014	1,000-9,999 GT
015	10,000-19,999 GT
016	20,000-34,999 GT
017	35,000-49,999 GT
018	50,000-99,999 GT
019	100,000 GT or more
030	Tank barge 0-149 GT
031	150-299 GT
032	300-499 GT
033	500-999 GT
034	1,000-9,999 GT
035	10,000-19,999 GT
036	20,000-34,999 GT
037	35,000-49,999 GT
038	50,000-99,999 GT
039	100,000 GT or more
050	Dry cargo ship
051	Dry cargo barge
052	Tugboat or towboat
053	Fishing vessel
054	Passenger vessel
055	Recreational vessel
056	Combatant vessel
057	Other public vessel

(b) Marine facility:

- 100 Other transportation-related marine facility
- 101 Onshore bulk cargo transfer
- 102 Onshore fueling
- 103 Onshore non-bulk cargo transfer
- 104 Offshore bulk cargo transfer
- 105 Offshore fueling
- 106 Offshore non-bulk cargo transfer

2. Land Transportation System

(a) Vehicles:

- 200 Other land vehicle or unknown type of land vehicle
- 201 Rail vehicle liquid bulk
- 202 Rail vehicle dry bulk
- 203 Rail vehicle general cargo
- 204 Rail vehicle transfer
- 205 Highway vehicle liquid bulk
- 206 Highway vehicle dry bulk
- 207 Highway vehicle general cargo
- 208 Highway vehicle passenger

(b) Land facilities:

- 300 Other land transportation facility or unknown type of land transportation facility
- 301 Railway cargo transfer
- 302 Railway fueling facility
- 303 Highway cargo transfer
- 304 Highway fueling

(c) Transportation-related pipelines:

- 400 Other pipeline
- 401 Onshore pipeline
- 402 Offshore pipeline

(d) Non-transportation-related facilities:

- 500 Other onshore non-transportation-related facility
- 501 Onshore refinery
- 502 Onshore bulk storage facility (includes tank farms)
- 503 Onshore industrial plant or processing facility
- 504 Onshore oil or gas production facility
- 505 Other offshore non-transportation-related facility
- 506 Offshore production facility

(e) Miscellaneous:

900 Miscellaneous—or natural source—any source not listed above. (Use this code if cause is natural seepage or if material is natural substance.)

999 Unknown type of source.

CAUSE

Enter two letters to indicate the cause of a pollution incident. Use the first position to indicate the immediate cause of a discharge, i.e., the manner in which a pollutant actually escaped a tank, conduit, well, etc. Use the second position to indicate the most significant factor which contributed to the event indicated in the first position. Immediate causes and contributing factors are arranged under five basic categories: (1) structural failure or loss; (2) equipment failure; (3) personnel error (unintentional); (4) intentional discharge; and (5) natural or chronic phenomenon. An immediate cause and contributing factor must be selected from the same category. Use the following code:

1. Structural Failure or Loss

<u>Immediate Cause</u>		<u>Contributing Factor</u>	
A	Hull rupture or lead	A	Collision
B	Tank rupture or leak	B	Grounding
C	Transportation pipeline rupture or leak	C	Fire/explosion
D	Dike rupture or lead	D	Capsizing/overturning
E	Container lost intact	E	Sinking
F	Well blow-out	F	Other casualty
		G	Adverse weather or sea conditions
H	Other structural failure	H	Earthquake or other natural disaster
		I	Minor damage
		J	Material fault
		K	Design fault
		L	Personnel error (PE) improper maintenance
		M	PE - overpressurization
		N	Other personnel error
		Q	Other or unknown factor

2. Equipment Failure

<u>Immediate Cause</u>	<u>Contributing Factor</u>
I Pipe rupture or lead	A Minor damage
J Hose rupture or leak	B Excessive wear
K Manifold rupture or lead	C Corrosion
L Loading arm failure, rupture or lead	D Material fault
M Valve failure	E Design fault
N Pump failure	F PE - improper installation
O Flange failure	G PE - improper maintenance
P Gasket failure	H PE - hose, pipe, or loading arm cut or severed
R Other equipment failure	I PE - hose, pipe, or loading arm twisted or kinked
	J PE - improper valve operation
	K PE - flanges improperly secured
	L PE - overpressurization
	M Other personnel error
	P Other or unknown factor

3. Personnel Error (Unintentional Discharge)

<u>Immediate Cause</u>	<u>Contributing Factor</u>
S Tank overflow	A Inadequate sounding
T Improper equipment handling or operation	B Failure to shut down
W Other personnel error	C Topping off at excessive rate
	D Loading too many tanks simultaneously
	E Overfilling (and subsequent overflow)
	F Improper hose handling
	G Improper valve operation
	H Flanges improperly secured
	K Other or unknown factor

4. Intentional Discharge

<u>Immediate Cause</u>	<u>Contributing Factor</u>
X Intentional discharge	A Bilge pumping
	B Ballast pumping
	C Tank cleaning or stripping
	D Emergency discharge
	E Disposal of waste
	F Discharge under COE/EPA permit
	G Sabotage or vandalism
	H Salvage operations
	J Other or unknown factor

5. Natural or Chronic Phenomenon

<u>Immediate Cause</u>		<u>Contributing Factor</u>	
Y	Natural or chronic phenomenon	A	Natural seepage from sea bottom
		B	Natural substance reported as oil slick
		C	Leaching from saturated ground
		E	Other factor.

APPENDIX B

DEFINITION OF A TRANSPORTATION-RELATED FACILITY

(Based on Environmental Protection Agency/Department of Transportation Memorandum of Understanding, dated 24 November 1971).

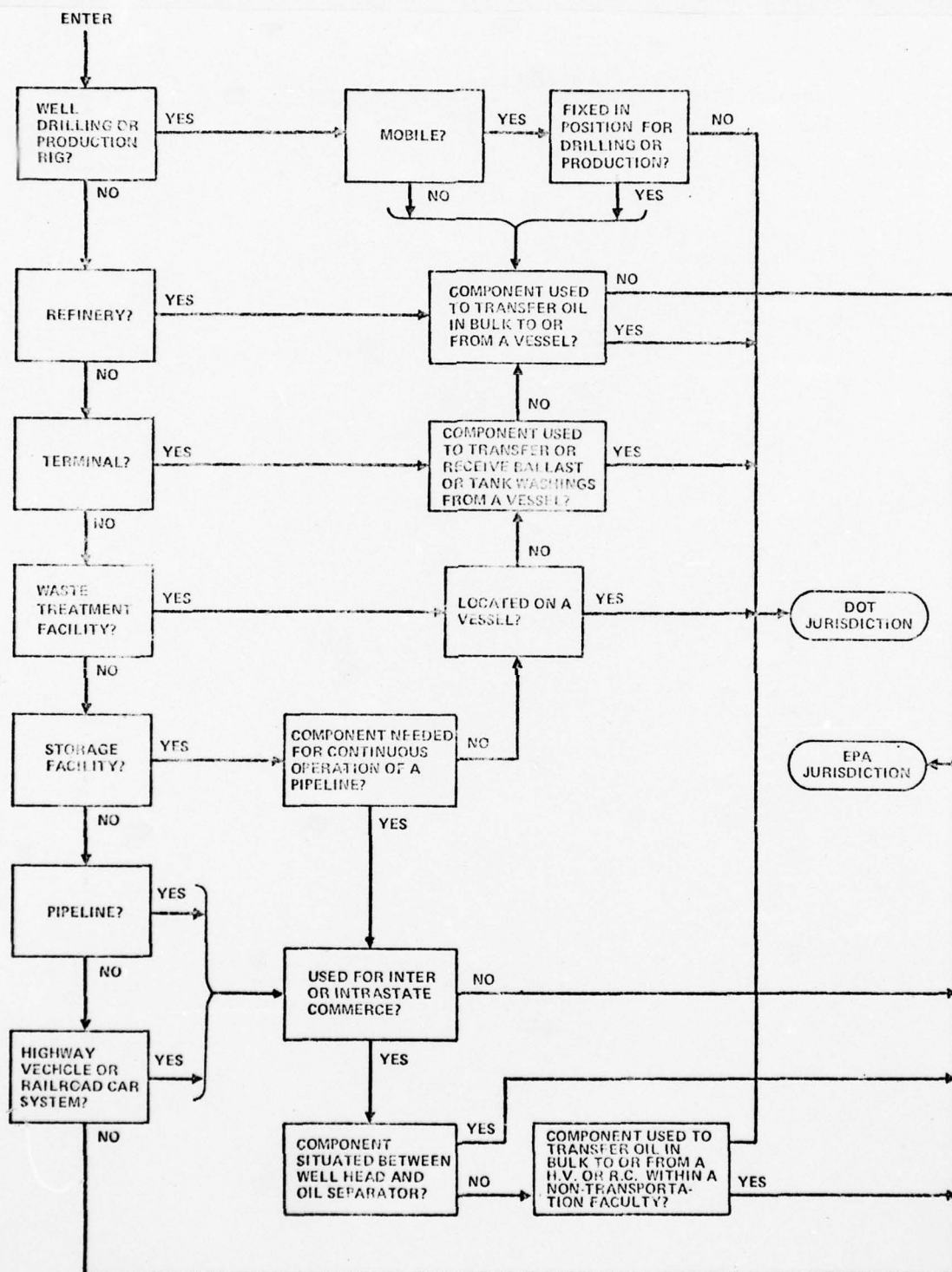


FIGURE B.1. DECISION DIAGRAM FOR DETERMINING REGULATORY RESPONSIBILITY FOR FACILITIES

WELL DRILLING AND PRODUCTION FACILITIES

- DOT Responsibility — Any facility or unit which integrally associates with the handling or transfer of oil in bulk to or from a vessel.
- EPA Responsibility — All other facilities and related equipment on-shore or offshore, fixed or mobile (when fixed in position for drilling or production).

REFINERIES

- DOT Responsibility — Any facility or unit which integrally associates with the handling or transfer of oil in bulk to or from a vessel.
- EPA Responsibility — All other facilities and related equipment including storage tanks, piping, and drainage systems and waste treatment units.

TERMINALS

- DOT Responsibility — All facilities and related equipment used for the purpose of transferring oil in bulk to or from a vessel or to receive oily ballast or tank washings from a vessel.
- EPA Responsibility — Terminal waste treatment and oil storage facilities.

WASTE TREATMENT FACILITIES

- DOT Responsibility — Facilities located on vessels and terminal facilities used to receive oily ballast and tank washings from a vessel.
- EPA Responsibility — All other waste treatment facilities including in-plant pipelines, effluent discharge lines and storage tanks.

STORAGE FACILITIES

- DOT Responsibility — In-line and breakout tanks needed for the continuous operation of pipeline systems.
- EPA Responsibility — All other facilities and related equipment for bulk, terminal, or consumer storage.

6. PIPELINES

DOT Responsibility - All systems and related equipment, onshore or offshore which are used for interstate or intrastate commerce including pipelines from production facilities.

EPA Responsibility - Onshore and offshore pipelines from wellheads oil separators and pieplines used exclusively to transfer oil within a non-transportation related facility.

7. HIGHWAY VEHICLES AND RAILROAD CARS

DOT Responsibility - All such conveyances and related equipment which are used for interstate or intrastate commerce, including the right-of-way on which they operate.

EPA Responsibility - All such conveyances which are used exclusively within the confines of a non-transportation related facility (refinery, tank frame, etc.). All hoses and other equipment used to transfer oil in bulk, to or from highway vehicles or railroad cars at such a facility.

8. CONSUMING FACILITIES

DOT Responsibility - In-line and breakout tanks needed for the continuous operation of pipeline systems.

EPA Responsibility - All other industrial, commercial, agricultural or public facilities which use or store oil.

APPENDIX C DOCUMENTATION

The analysis is based on 36 distributions which were extracted from the 1971-1973 PIRS data. These distributions, and that portion of the PIRS population which each addresses, are indicated by the hexagonal blocks in Figure C.1. A listing of the categories of information being collated in each distribution is given followed by the distributions themselves.

Set I addresses all of the PIRS data by general source and cause, the distribution of all incidents reported, the number and percent of total where quantity spilled was recorded, and the distribution of volume and average spills that resulted. Both absolute and frequency distributions are computed.

Set II addresses only those incidents and that volume arising from "preventable" causes (i.e., excluding natural phenomena). The distributions in Set II parallel those in Set I, breaking causes and the vessel source grouping into finer categories. Set III addresses the distributions of pollution incidents and the volume discharged for each general source group according to the size of the spills.

Set IV shows the same kind of distribution as Set III, but excluding all incidents smaller than 1,000 gallons.

Sheet I of Set IV, examines the distribution of pollution incidents for each general source grouping according to the means by which the Coast Guard became aware, or was "notified," of the occurrence. The remaining sheets address the important vessel-casualty source/cause combination in greater detail.

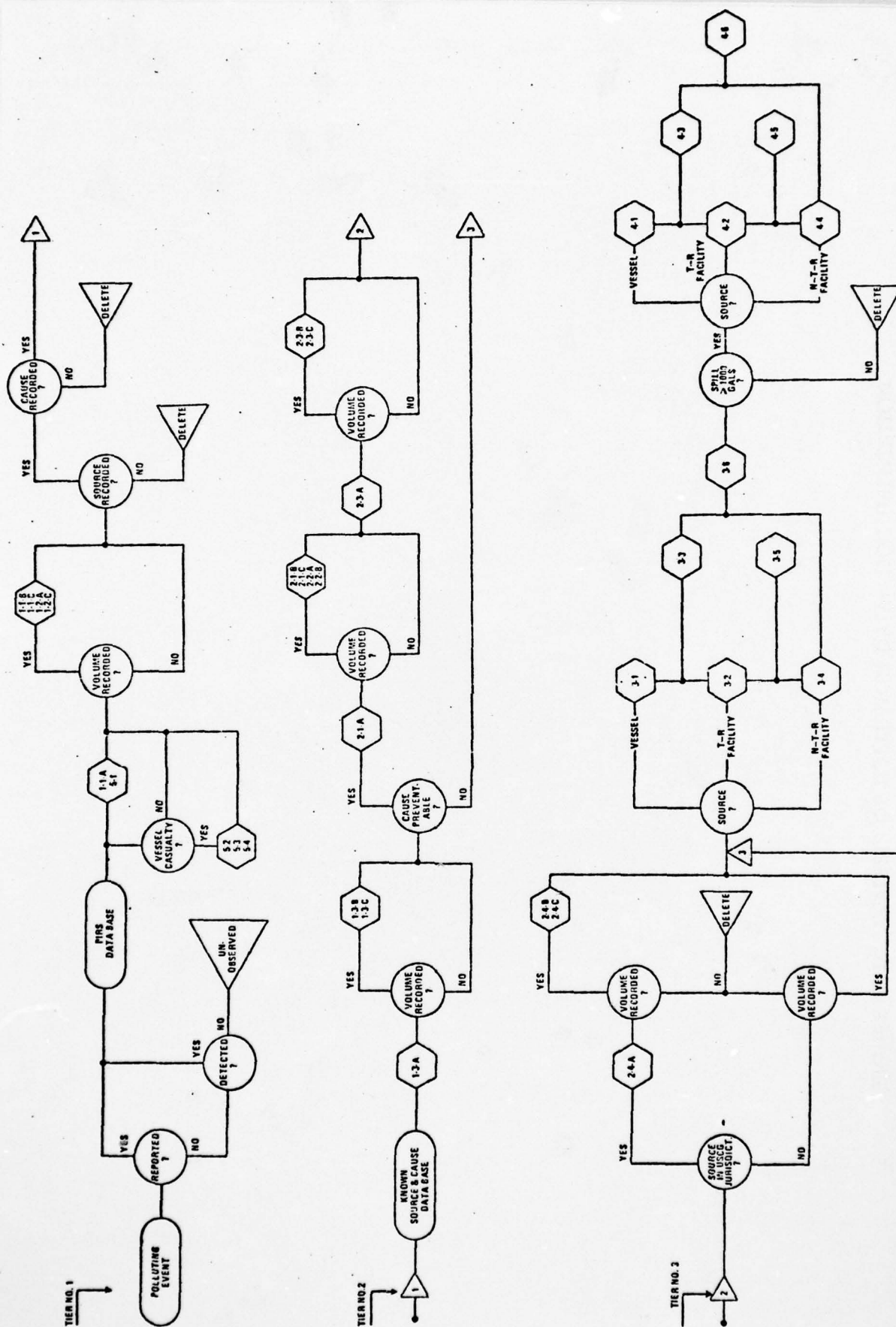


FIGURE C.1. ANALYSIS OF POLLUTION DATA: DOCUMENTATION

ANALYSIS OF POLLUTION DATA: DOCUMENTATION

Set	Sheet	Entry	Kind of Distribution
1	1	A	Incidents by source and general cause
1	1	B	Incidents by source and general cause (volume recorded)
1	1	C	Percentage of incidents where volume was recorded by source and general cause
1	2	A	Volume by source and general cause
1	2	B	Mean spillage per incident by source and general cause
1	3	A	Frequency of incidents per 1,000 by source and general cause
1	3	B	Frequency of incidents per 1,000 by source and general cause (volume recorded)
1	3	C	Frequency of volume per 1,000 by source and general cause
2	1	A	Incidents by source and specific cause
2	1	B	Incidents by source and specific cause (volume recorded)
2	1	C	Percentage of incidents where volume recorded by source and specific cause
2	2	A	Volume by source and specific cause
2	2	B	Mean spillage per incident by source and specific cause
2	3	A	Frequency of incidents per 1,000 by source and specific cause
2	3	B	Frequency of incidents per 1,000 by source and specific cause (volume recorded)
2	3	C	Frequency of volume per 1,000 by source and specific cause

Set	Sheet	Entry	Kind of Distribution
2	4	A	Frequency of incidents per 1,000 by source and specific cause
2	4	B	Frequency of incidents per 1,000 by source and specific cause (volume recorded)
2	4	C	Frequency of volume per 1,000 by source and specific cause
3	1-6		Frequency of incidents and of volume per 10,000 by size of spill (all spills)
4	1-6		Frequency of incidents and of volume by size of spill (spills greater than 1,000 gallons)
5	1		Incidents by source and notifier
5	2		Incidents of vessel casualties by type of vessel and specific cause
5	3		Volume from vessel casualties by type of vessel and specific cause
5	4		Mean spillage from vessel casualties by type of vessel and specific cause

SUMMARY OF 1971, 72, 73 INCIDENTS BY SOURCE AND CAUSE										SET #1		SHEET # 1	
CASUALTY MATERIAL/ PERSONNEL										TOTAL		TOTAL	
STRU/EQUIP										KNOW		UNKNOWN	
FAILURE										CAUSE		REPORTED	
FAILURE										DELIBERAT		PREVENTBL	
FAILURE										TOTAL		PHENOMENA	
FAILURE										TOTAL		TOTAL	
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SUMMARY OF 1971, 72, 73 VOLUME										BY SOURCE AND CAUSE				TOTAL		TOTAL		TOTAL		TOTAL		TOTAL	
CASUALTY										MATERIAL/ PERSONNEL		TOTAL		ACCIDENT DELIBERAT		PREVENTBL PHENOMENA		TOTAL		TOTAL		TOTAL	
										STRU/EQUIP		TOTAL		FAILURE		FAILURE		TOTAL		TOTAL		TOTAL	
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										FAILURE		TOTAL		FAILURE		FAILURE							

SUMMARY OF 1971, 72, 73 DISTRIBUTION BY SOURCE AND CAUSE

	CASUALTY MATERIAL/ PERSONNEL				TOTAL				TOTAL				SET 1		SHELTS		3			
	FAILURE	STRU/EQUIP	FAILURE	ACCIDENT DELIBERAT	FAILURE	ACCIDENT DELIBERAT	PREVENTBL	PHENOMENA	TOTAL	KNOWN	CAUSE	TOTAL	UNKNOWN	REPORTED						
VESSEL	35	27	123	124	147	155	305	307	47	37	352	343	4	3	356	347	88	68	444	415
	297		66		31		393		40		434		0		434		12		445	
TANKSHIP	16	13	93	94	74	80	183	187	8	7	191	194	2	2	193	196	26	20	220	216
	258		64		18		341		39		380		0	0	380		10		390	
OTHER	20	14	30	30	73	75	122	119	39	30	161	149	2	1	163	150	62	48	225	199
	39		1		13		52		1		54		0	0	54		2		56	
FACILITY	19	17	469	500	107	105	595	622	25	14	620	636	24	18	644	653	94	63	738	716
	16		232		55		304		11		314		252		566		39		605	
TRANSPORT	14	13	158	168	40	39	212	219	7	5	220	224	5	4	225	229	19	14	244	243
	12		133		10		156		1		157		24		181		12		193	
ONSHORE	13	11	59	59	38	37	110	107	7	5	117	112	5	4	122	116	18	14	141	130
	12		119		10		141		1		142		24		166		12		178	
MARINE	1	1	29	29	21	21	51	50	3	2	54	52	3	2	56	54	11	8	68	62
	0		47		5		52		0		52		23		75		4		79	
VEHICLE	11	10	7	7	14	13	32	29	4	3	36	32	2	2	38	34	6	4	44	38
	10		4		3		17		1		18		0		18		5		23	
PIPELINE	1	1	23	23	3	4	27	28	0	0	27	28	1	1	28	29	1	1	29	30
	2		68		2		72		0		72		1		73		3		76	
OFFSHORE	1	1	99	109	2	2	102	112	0	0	102	112	0	0	103	112	1	1	104	113
	0		15		0		15		0		15		0		15		0		15	
MARINE	0	0	9	10	1	1	11	12	0	0	11	12	0	0	11	12	1	0	12	12
	0		0		0		0		0		0		0		0		0		0	
PIPELINE	1	1	90	99	1	1	91	100	0	0	91	100	0	0	91	101	0	0	92	101
	0		14		0		15		0		15		0		15		0		15	
NON-TRANSPORT	5	4	311	332	68	67	383	403	18	8	401	411	18	14	419	425	75	48	494	473
	4		99		45		149		9		157		228		385		27		412	
ONSHORE	2	2	74	67	47	45	123	114	17	7	140	121	15	10	155	131	52	29	206	160
	3		89		44		136		9		145		228		373		11		384	
OFFSHORE	2	2	237	265	20	22	260	289	1	1	261	290	3	4	264	294	24	19	288	313
	1		10		1		12		0		12		0		12		16		28	
TOTAL KNOWN SOURCE	54	44	592	624	254	261	900	929	72	50	972	979	28	21	1000	1000	183	131	1183	1131
	313		298		86		697		51		748		252		1000		51		1051	
MISC/UNKNOWN	1	1	11	9	9	8	21	17	6	4	27	22	14	6	41	28	513	236	555	264
	7		140		1		147		1		149		0		149		19		168	
TOTAL REPORTED	56	45	603	633	263	268	922	946	78	54	1000	1001	42	27	1041	1028	696	367	1737	1395
	319		438		87		844		53		896		253		1149		70		1219	
TOTAL DCT JURIS.	49	40	281	292	187	194	517	526	55	42	572	568	7	7	581	575	108	82	689	658
	309		199		41		549		42		591		24		615		23		638	

SUMMARY OF 1971-72, 73 INCIDENTS

[illegible]

SUMMARY OF 1971 72.73 VOLUME	BY SOURCE AND CAUSE				EQUIP, MATL, CR, STRUCT FAILURE				TOTAL E, PERSONNEL/CC/EP/PA				DELIBERATE DISCHARGE				TOTAL PREVENTABLE	
	COLLISION GROUNDING		CASUALTY		WELL BLOWOUT		TOTAL CASUALTY		TANK		PUMP CR VALVE		OTHER		M/S FAIL			NOT PERMITTED
VESSEL	624650	2335050	2032908	42	42	2452430	147365	212967	83052	2450515	2693899	1358748	0	1780308	1780308	1910035	0	1910035
	44302	24073	145208	42	42	12976	29564	429	189	3162	1430	536	0	2907	2907	3420	0	3420
TANKSHIP/BARGE	535871	2291501	2025325	42	42	1695371	11371110	195795	72472	2426186	2830137	803993	0	1728675	1728675	16737515	0	16737515
	51037	32736	506331	42	42	51375	53385	529	224	4260	1844	619	0	16156	16156	9304	0	9304
LT 104	61164	357874	250	42	42	3124	972954	1474	3781	134749	184510	58851	0	1459	1459	121774	0	121774
	23526	14315	250	42	42	391	15950	32	135	633	563	163	0	56	56	1569	0	1569
10-104	841180	322262	0	0	0	850	1164292	5770	6488	65015	91697	62691	0	1723186	1723186	3041664	0	3041664
	120169	107421	0	0	0	425	97024	412	138	1275	664	259	0	50682	50682	7204	0	7204
35-1004	110005	0	0	0	0	500	1100505	130	5444	1085	10913	22886	0	1	1	1134305	0	1134305
	550003	0	0	0	0	500	366635	130	302	121	352	545	0	1	1	14751	0	14751
GT 1004	0	0	0	0	0	0	0	0	75	1294	1369	357	0	200	200	1926	0	1926
	0	0	0	0	0	0	0	0	75	431	342	60	0	200	200	175	0	175
UNANN'D DISPL	2806022	1611365	2025075	0	0	1690997	8133359	132651	56684	2226003	2545648	659208	0	3829	3829	11342044	0	11342044
	40086	38366	675025	0	0	76859	53368	436	246	7571	2448	1017	0	85	85	6065	0	6065
OTHER	667779	43549	7583	0	0	757059	1695970	9681	17172	10580	22329	59762	0	51633	51633	2364120	0	2364120
	24661	1613	758	0	0	4853	7806	208	91	109	123	453	0	106	106	972	0	972
TRANSPORT FACILITY	183396	225	314615	48	48	35421	533725	3819802	95359	1365091	5868750	459220	7	60873	60873	6022575	0	6022575
	2158	75	3658	23	23	1312	2616	1796	276	6627	2150	725	4	742	742	1696	0	1696
CAS-CHE	169083	225	316615	50	50	31281	512554	3203113	49940	1361777	5223323	457578	7	60868	60873	6257030	0	6257030
	2254	75	3658	50	50	1422	2755	5200	614	7545	5452	763	4	751	753	3423	0	3423
MARINE	2363	0	0	50	50	90	2503	548931	13521	973653	2055797	237687	0	6046	6046	2304233	0	2304233
	236	0	0	50	50	30	179	20331	159	10563	4374	705	0	224	224	2715	0	2715
VEHICLE	91471	225	316565	0	0	20267	426528	39562	47337	41270	166454	139619	7	45762	45769	776510	0	776510
	1550	75	3701	0	0	1267	2617	1884	2491	1587	1570	679	4	933	936	1480	0	1480
PIPELINE	75249	0	50	0	0	10924	86223	0	9082	346854	3001072	80072	0	9120	9120	3176487	0	3176487
	12542	0	50	0	0	3641	8622	0	908	5594	7856	1405	0	1824	1824	6997	0	6997
CAS-CHE	14313	0	0	18	18	4140	18471	5	25419	3314	645427	1642	0	5	5	665545	0	665545
	1431	0	0	9	9	828	1087	2	110	127	364	50	0	5	5	365	0	365
MARINE	0	0	0	0	0	5	5	3	15959	2272	949	19203	0	5	5	20575	0	20575
	0	0	0	0	0	5	5	3	67	57	116	62	0	5	5	109	0	109
PIPELINE	14313	0	0	18	18	4135	18466	2	23147	2345	626224	280	0	0	0	644970	0	644970
	1431	0	0	9	9	1034	1154	1	117	261	390	25	0	0	0	305	0	305
TOTAL, OCT JUMIS	6430046	2335275	2347523	110	110	2467651	13600605	758853	178411	3815666	8762649	1817968	7	1801181	1801181	26222610	0	26222610
	28452	23353	23475	28	28	11518	21054	2027	227	3890	1844	576	4	2716	2716	2618	0	2618
NEW-TRANS-FACILITY	3661	20001	4030	17700	17700	129451	174313	1344227	29775	384584	4363215	1968679	11298	394500	405798	6913205	0	6913205
	146	10001	1008	4443	4443	3082	2388	564	193	280	808	1821	1612	3082	2884	1034	0	1034
TOTAL, UNANN SOURCE	6433107	2355276	2351553	17800	17800	2467302	13775118	5376994	476186	4200190	13125664	3787847	11305	2235661	2246886	32935615	0	32935615
	26045	23091	22611	2235	2235	10145	19159	1074	204	1819	1293	894	1131	2774	2754	2568	0	2568

SLT#2 SHEET# 3

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AD-A042 978

OPERATIONS RESEARCH INC SILVER SPRING MD RESOURCE AN--ETC F/G 13/2
SPILL RISK ANALYSIS PROGRAM: METHODOLOGY DEVELOPMENT AND DEMONS--ETC(U)
APR 77 W D WHITE, L A STOEHR DOT-CG-31571-A

UNCLASSIFIED

ORI-TR-964-VOL-2

USCG-D-22-77

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SUMMARY OF 1971 72,73 DISTRIBUTION BY SOURCE AND CAUSE

[illegible]

VESSELS CLASS INTERVAL (GALLONS)	INCIDENTS			VOLUME			SET-3 SHEET-1	
	NUMBER	FREQUENCY	1-CUM FREQUENCY	SPILLAGE	FREQUENCY	1-CUM FREQUENCY	AVERAGE SPILL	CLASS MARK
1- 99	4137	7339	2661	87172	46	9954	21.1	50
100- 199	440	761	1880	53619	28	9926	121.9	150
200- 299	310	550	1330	66202	35	9891	213.6	250
300- 399	95	169	1161	29815	16	9875	313.8	350
400- 599	187	332	829	82657	43	9832	442.0	500
600- 799	55	98	731	35547	19	9813	646.3	700
800- 999	43	76	655	35790	19	9794	832.3	900
1000- 1999	119	211	444	142710	75	9719	1199.2	1500
2000- 2999	51	90	354	111030	58	9661	2177.1	2500
3000- 3999	24	43	311	77799	41	9620	3241.6	3500
4000- 5999	49	87	224	220208	115	9505	4494.0	5000
6000- 7999	18	32	192	119715	63	9442	6650.8	7000
8000- 9999	13	23	169	107446	56	9386	8265.1	9000
10000- 19999	21	37	132	275810	144	9242	13133.8	15000
20000- 29999	13	23	109	303000	159	9083	23307.7	25000
30000- 39999	5	9	100	180658	95	8988	36131.6	35000
40000- 59999	9	16	84	434054	227	8761	48228.2	50000
60000- 79999	8	14	70	517000	271	8490	64625.0	70000
80000- 99999	6	11	59	508522	266	8224	84753.6	90000
100000- 199999	14	25	34	1934072	1012	7212	138148.0	150000
200000- 299999	7	12	22	1529446	800	6412	218492.3	250000
300000- 399999	5	9	13	1754000	918	5494	350800.0	350000
400000- 599999	1	2	11	525000	275	5219	525000.0	500000
600000- 799999	0	0	11	0	0	5219	0.0	700000
800000- 999999	2	4	7	1690000	884	4335	845000.0	900000
1000000- 1999999	3	5	2	4265910	2243	2092	1428636.0	1499999
2000000-*****	2	4	-1	4000000	2093	0	2000000.0	*****
CVEHALL	5637	10002	-1	19107182	10001	0	3389.6	

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TRANSPORT FACILITIES CLASS INTERVAL (GALLONS)	INCIDENTS	1-CUM FREQUENCY	SPILLAGE	VOLUME FREQUENCY	1-CUM FREQUENCY	AVERAGE SPILL	SET#3 SHEET CLASS MARK
1- 99	2536	6819	3181	50626	63	9937	20.0
100- 199	261	702	2479	33269	42	9895	127.5
200- 299	192	516	1963	42613	53	9842	221.9
300- 399	51	137	1826	16329	20	9822	320.2
400- 599	140	398	1428	66112	83	9739	446.7
600- 799	63	169	1259	40200	50	9689	638.1
800- 999	58	156	1103	48857	61	9628	842.4
1000- 1999	117	315	788	148691	186	9442	1270.9
2000- 2999	61	164	624	134921	169	9273	2211.8
3000- 3999	42	113	511	135870	170	9103	3235.0
4000- 5999	63	169	342	283420	355	8748	4498.7
6000- 7999	31	83	259	206280	259	8489	6654.2
8000- 9999	20	54	205	170192	213	8276	8509.6
10000- 19999	31	83	122	359827	451	7825	11607.3
20000- 29999	14	38	84	327490	411	7414	23392.1
30000- 39999	4	11	73	137436	172	7242	34359.0
40000- 59999	10	27	46	438000	549	6693	43800.0
60000- 79999	0	0	46	0	0	6693	0.0
80000- 99999	1	3	43	95000	119	6574	95000.0
100000- 199999	9	24	19	1345540	1687	4887	149504.4
200000- 299999	2	5	14	483000	606	4281	241500.0
300000- 399999	0	0	14	0	0	4281	0.0
400000- 599999	3	8	6	1445000	1812	2469	481666.6
600000- 799999	0	0	6	0	0	2469	0.0
800000- 999999	1	3	3	960000	1204	1265	960000.0
1000000- 1999999	1	3	0	1008000	1264	1	1008000.0
2000000-*****	0	0	0	0	0	1	0.0
OVERALL	3719	10000	0	7976673	9999	1	2144.8

OCT JURISDICTION CLASS INTERVAL (GALLONS)	INCIDENTS			VOLUME			SET#3 SHEET#3	
	NUMBER	FREQUENCY	1-CUM FREQUENCY	SPILLAGE	FREQUENCY	1-CUM FREQUENCY	AVERAGE SPILL	CLASS MARK
1-	99	6673	7132	2868	137798	51	9949	50
100-	199	701	749	2119	86888	32	9917	150
200-	299	502	537	1582	108815	40	9877	250
300-	399	146	156	1426	46144	17	9860	350
400-	599	335	358	1068	148769	55	9805	500
600-	799	118	126	942	75747	28	9777	700
800-	999	101	108	834	84647	31	9746	900
1000-	1999	236	252	582	291401	108	9638	1500
2000-	2999	112	120	462	245951	91	9547	2500
3000-	3999	66	71	391	213669	79	9468	3500
4000-	5999	112	120	271	503628	186	9282	5000
6000-	7999	49	52	219	325995	120	9162	7000
8000-	9999	33	35	184	277638	103	9059	9000
10000-	19999	52	56	128	635637	235	8824	15000
20000-	29999	27	29	99	630490	233	8591	25000
30000-	39999	9	10	89	318094	117	8474	35000
40000-	59999	19	20	69	872054	322	8152	50000
60000-	79999	8	9	60	517000	191	7961	70000
80000-	99999	7	7	53	603522	223	7738	90000
100000-	199999	23	25	28	3279612	1211	6527	150000
200000-	299999	9	10	18	2012446	743	5784	250000
300000-	399999	5	5	13	1754000	648	5136	350000
400000-	599999	4	4	9	1970000	727	4409	500000
600000-	799999	0	0	9	0	0	4409	700000
800000-	999999	3	3	6	2650300	978	3431	900000
1000000-	1999999	4	4	2	5293910	1955	1476	1499999
2000000-*****		2	2	0	4000000	1477	0	*****
OVERALL		9356	10000	0	27083855	10001	0	
							2894.8	

NON-TRANSPORT FACILITIES CLASS INTERVAL (GALLONS)	INCIDENTS			VOLUME			SET#3 SHEET#4	
	NUMBER	FREQUENCY	1-CUM FREQUENCY	SPILLAGE	FREQUENCY	1-CUM FREQUENCY	AVERAGE SPILL	CLASS MARK
1-	99	5475	7923	2077	45717	56	9944	17.5
100-	199	467	676	1401	61568	36	9908	131.8
200-	299	230	333	1068	50846	30	9878	221.1
300-	399	97	140	928	31272	18	9860	322.4
400-	599	176	255	673	78984	47	9813	448.8
600-	799	60	87	586	38953	23	9790	649.2
800-	999	52	75	511	44035	26	9764	846.8
1000-	1999	102	148	363	124063	73	9691	1216.3
2000-	2999	52	75	288	113961	67	9624	2191.6
3000-	3999	20	29	259	63655	38	9586	3182.8
4000-	5999	44	64	195	200620	118	9468	4559.5
6000-	7999	27	39	156	173780	102	9366	6436.3
8000-	9999	11	16	140	93900	55	9311	8536.4
10000-	19999	37	54	86	473888	279	9032	12807.8
20000-	29999	17	25	61	366074	216	8816	21533.8
30000-	39999	10	14	47	315200	186	8630	31520.0
40000-	59999	12	17	30	555160	327	8303	46263.3
60000-	79999	6	9	21	396460	234	8069	66076.6
80000-	99999	6	9	12	520000	307	7762	86666.6
100000-	199999	2	3	9	298000	176	7586	149000.0
200000-	299999	4	6	3	866800	511	7075	216700.0
300000-	399999	0	0	3	0	0	7075	0.0
400000-	599999	0	0	3	0	0	7075	0.0
600000-	799999	0	0	3	0	0	7075	0.0
800000-	999999	0	0	3	0	0	7075	0.0
1000000-	1999999	0	0	3	0	0	7075	0.0
2000000-	*****	3	4	0	1200000	7074	1	400000.0
OVERALL		6910	10001	0	16962936	9999	1	2454.8

ALL FACILITIES CLASS INTERVAL (GALLONS)	INCIDENTS			VOLUME			SET#3 SHEETS	
	NUMBER	FREQUENCY	1-CUM FREQUENCY	SPIPAGE	FREQUENCY	1-CUM FREQUENCY	AVERAGE SPILL	CLASS MARK
1- 99	8011	7537	2463	146343	59	9941	18.3	50
100- 199	728	685	1778	94837	38	9903	130.3	150
200- 299	422	397	1381	93459	37	9866	221.5	250
300- 399	148	139	1242	47601	19	9847	321.6	350
400- 599	324	305	937	145096	58	9789	447.8	500
600- 799	123	116	821	79153	32	9757	643.5	700
800- 999	110	103	718	92892	37	9720	844.5	900
1000- 1999	219	206	512	272754	109	9611	1245.5	1500
2000- 2999	113	106	406	248882	100	9511	2202.5	2500
3000- 3999	62	58	348	199525	80	9431	3218.1	3500
4000- 5999	107	101	247	484040	194	9237	4523.7	5000
6000- 7999	58	55	192	380060	152	9085	6552.8	7000
8000- 9999	31	29	163	264092	106	8979	8519.1	9000
10000- 19999	68	64	99	833715	334	8645	12260.5	15000
20000- 29999	31	29	70	693564	278	8367	22373.0	25000
30000- 39999	14	13	57	452636	181	8186	32331.1	35000
40000- 59999	22	21	36	993160	398	7788	45143.6	50000
60000- 79999	6	6	30	396460	159	7629	66076.6	70000
80000- 99999	7	7	23	615000	247	7382	87857.1	90000
100000- 199999	11	10	13	1643540	659	6723	149412.7	150000
200000- 299999	6	6	7	1349800	541	6182	224966.6	250000
300000- 399999	0	0	7	0	0	6182	0.0	350000
400000- 599999	3	3	4	1445000	579	5603	481666.6	500000
600000- 799999	0	0	4	0	0	5603	0.0	700000
800000- 999999	1	1	3	960000	365	5218	960000.0	900000
1000000- 1999999	1	1	2	1008000	404	4814	1008000.0	1499999
2000000-*****	3	3	0	1200000	4812	2	4000000.0	*****
OVERALL	10629	10001	0	24939609	9998	2	2346.4	

ALL PIPS DATA CLASS INTERVAL (GALLONS)	INCIDENTS			VOLUME			SET#3 SHEET#6	
	NUMBER	FREQUENCY	1-CUM FREQUENCY	SPILLAGE	FREQUENCY	1-CUM FREQUENCY	AVERAGE SPILL	CLASS MARK
1- 99	12148	7468	2532	233515	53	9947	19.2	50
100- 199	1168	718	1814	148456	34	9913	127.1	150
200- 299	732	450	1364	159661	36	9877	218.1	250
300- 399	243	149	1215	77416	18	9859	318.6	350
400- 599	511	314	901	227753	52	9807	445.7	500
600- 799	178	109	792	114700	26	9781	644.4	700
800- 999	153	94	698	128682	29	9752	841.1	900
1000- 1999	338	208	490	415464	94	9658	1229.2	1500
2000- 2999	164	101	389	359912	82	9576	2194.6	2500
3000- 3999	86	53	336	277324	63	9513	3224.7	3500
4000- 5999	156	96	240	704248	160	9353	4514.4	5000
6000- 7999	76	47	193	499775	113	9240	6576.0	7000
8000- 9999	44	27	166	371538	84	9156	8444.0	9000
10000- 19999	89	55	111	1109525	252	8904	12466.6	15000
20000- 29999	44	27	84	996564	226	8678	22649.2	25000
30000- 39999	19	12	72	633294	144	8534	33331.3	35000
40000- 59999	31	19	53	1427214	324	8210	46039.2	50000
60000- 79999	14	9	44	913460	207	8003	65247.1	70000
80000- 99999	13	8	36	1123522	255	7748	86424.8	90000
100000- 199999	25	15	21	3577612	812	6936	143104.4	150000
200000- 299999	13	8	13	2879246	654	6282	221480.4	250000
300000- 399999	5	3	10	1754000	398	5884	350800.0	350000
400000- 599999	4	2	8	1970000	447	5437	492500.0	500000
600000- 799999	0	0	8	0	0	5437	0.0	700000
800000- 999999	3	2	6	2650000	602	4835	863333.3	900000
1000000- 1999999	4	2	4	5293910	1202	3633	1323477.0	1499999
2000000-*****	5	3	1	16000000	3633	0	3200000.0	*****
OVERALL	16266	9999	1	44046791	10000	0	2707.9	

VESSELS CLASS INTERVAL (GALLONS)	INCIDENTS			VOLUME			SET#4 SMLET#1	
	NUMBER	FREQUENCY	1-CUM FREQUENCY	SPILLAGE	FREQUENCY	1-CUM FREQUENCY	AVERAGE SPILL	CLASS MARK
1000- 1999	119	3216	6784	142710	76	9924	1199.2	1500
2000- 2999	51	1378	5406	111030	59	9865	2177.1	2500
3000- 3999	24	649	4757	77799	42	9823	3241.6	3500
4000- 5999	49	1324	3433	220208	118	9705	4494.0	5000
6000- 7999	18	486	2947	119715	64	9641	6650.8	7000
8000- 9999	13	351	2596	107446	57	9584	8265.1	9000
10000- 19999	21	568	2028	275810	147	9437	13133.8	15000
20000- 29999	13	351	1677	303000	162	9275	23307.7	25000
30000- 39999	5	135	1542	180658	97	9178	36131.6	35000
40000- 59999	9	243	1299	434054	232	8946	48228.2	50000
60000- 79999	8	216	1083	517000	276	8670	64625.0	70000
80000- 99999	6	162	921	508522	272	8348	84753.6	90000
100000- 199999	14	378	543	1934072	1033	7365	138148.0	150000
200000- 299999	7	189	354	1529446	817	6548	218492.3	250000
300000- 399999	5	135	219	1754000	937	5611	350800.0	350000
400000- 599999	1	27	192	525000	281	5330	525000.0	500000
600000- 799999	0	0	192	0	0	5330	0.0	700000
800000- 999999	2	54	138	1690000	903	4427	845000.0	900000
1000000- 1999999	3	81	57	4285910	2290	2137	1428636.0	1499999
2000000- 2999999	2	54	3	4000000	2137	0	2000000.0	2499999
3000000- 3999999	0	0	3	0	0	0	0.0	3499999
4000000- 5999999	0	0	3	0	0	0	0.0	4999999
6000000- 7999999	0	0	3	0	0	0	0.0	6999999
8000000- 9999999	0	0	3	0	0	0	0.0	8999999
10000000- 19999999	0	0	3	0	0	0	0.0	14999999
20000000- 29999999	0	0	3	0	0	0	0.0	24999999
30000000-*****	0	0	3	0	0	0	0.0	*****
OVERALL	370	9997	3	18716380	10000	0	50584.8	

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TRANSPORT FACILITIES		INCIDENTS			VOLUME			SET#4 SHEET#2	
CLASS INTERVAL	(GALLONS)	NUMBER	FREQUENCY	1-CUM FREQUENCY	SPILLAGE	FREQUENCY	1-CUM FREQUENCY	AVERAGE SPILL	CLASS MARK
1000-	1999	117	2854	7146	148691	194	9806	1270.9	1500
2000-	2999	61	1488	5658	821	176	9630	2211.8	2500
3000-	3999	42	1024	4634		177	9453	3235.0	3500
4000-	5999	63	1537	3097	28420	369	9084	4498.7	5000
6000-	7999	31	756	2341	206280	269	8815	6654.2	7000
8000-	9999	20	488	1853	170192	222	8593	8509.6	9000
10000-	19999	31	756	1097	359827	469	8124	11607.3	15000
20000-	29999	14	341	756	327490	426	7698	23392.1	25000
30000-	39999	4	98	658	137436	179	7519	34359.0	35000
40000-	59999	10	244	414	438000	570	6949	43800.0	50000
60000-	79999	0	0	414	0	0	6949	0.0	70000
80000-	99999	1	24	390	95000	124	6825	95000.0	90000
100000-	199999	9	220	170	1345540	1752	5073	149504.4	150000
200000-	299999	2	49	121	483000	629	4444	241500.0	250000
300000-	399999	0	0	121	0	0	4444	0.0	350000
400000-	599999	3	73	48	1445000	1882	2562	481666.6	500000
600000-	799999	0	0	48	0	0	2562	0.0	700000
800000-	999999	1	24	24	960000	1250	1312	960000.0	900000
1000000-	1999999	1	24	0	1008000	1313	0	1008000.0	1499999
2000000-	2999999	0	0	0	0	0	0	0.0	2499999
3000000-	3999999	0	0	0	0	0	0	0.0	3499999
4000000-	5999999	0	0	0	0	0	0	0.0	4999999
6000000-	7999999	0	0	0	0	0	0	0.0	6999999
8000000-	9999999	0	0	0	0	0	0	0.0	8999999
10000000-	19999999	0	0	0	0	0	0	0.0	14999999
20000000-	29999999	0	0	0	0	0	0	0.0	24999999
30000000-	*****	0	0	0	0	0	0	0.0	*****
OVERALL		410	10000	0	7678667	10001	0	18728.5	

OCT JURISDICTION CLASS INTERVAL (GALLONS)	INCIDENTS			VOLUME			SET#4 SHEET#3	
	NUMBER	FREQUENCY	1-CUM FREQUENCY	SPIPAGE	FREQUENCY	1-CUM FREQUENCY	AVERAGE SPILL	CLASS MARK
1000- 1999	236	3026	6974	291401	110	9890	1234,8	1500
2000- 2999	112	1436	5538	245951	93	9797	2196,0	2500
3000- 3999	66	846	4692	213669	81	9716	3237,4	3500
4000- 5999	112	1436	3256	503628	191	9525	4496,7	5000
6000- 7999	49	628	2628	325995	124	9401	6653,0	7000
8000- 9999	33	423	2205	277638	105	9296	8413,3	9000
10000- 19999	52	667	1538	635637	241	9055	12223,8	15000
20000- 29999	27	346	1192	630490	239	8816	23351,5	25000
30000- 39999	9	115	1077	318094	121	8695	35343,6	35000
40000- 59999	19	244	833	872054	330	8365	45897,6	50000
60000- 79999	8	103	730	517000	196	8169	64625,0	70000
80000- 99999	7	90	640	603522	229	7940	86217,4	90000
100000- 199999	23	295	345	3279612	1243	6697	142591,8	150000
200000- 299999	9	115	230	2012446	762	5935	223605,1	250000
300000- 399999	5	64	166	1754000	665	5270	350800,0	350000
400000- 599999	4	51	115	1970000	746	4524	492500,0	500000
600000- 799999	0	0	115	0	0	4524	0,0	700000
800000- 999999	3	38	77	2650000	1004	3520	883333,3	900000
1000000- 1999999	4	51	26	5293910	2006	1514	1323477,0	1499999
2000000- 2999999	2	26	0	4000000	1515	0	2000000,0	2499999
3000000- 3999999	0	0	0	0	0	0	0,0	3499999
4000000- 5999999	0	0	0	0	0	0	0,0	4999999
6000000- 7999999	0	0	0	0	0	0	0,0	6999999
8000000- 9999999	0	0	0	0	0	0	0,0	8999999
10000000- 19999999	0	0	0	0	0	0	0,0	14999999
20000000- 29999999	0	0	0	0	0	0	0,0	249999984
30000000- *****	0	0	0	0	0	0	0,0	*****
CUMALL	780	10000	0	26395047	10001	0	33839,8	

NA-TRANSPORT FACILITIES CLASS INTERVAL (GALLONS)	INCIDENTS			VOLUME			SET#4 SHEET#4	
	NUMBER	FREQUENCY	1-CUM FREQUENCY	SPILLAGE	FREQUENCY	1-CUM FREQUENCY	AVERAGE SPILL	CLASS MARK
1000- 1999	102	2890	7110	124063	75	9925	1216,3	1500
2000- 2999	52	1473	5637	113961	69	9856	2191,6	2500
3000- 3999	20	567	5070	63655	38	9818	3182,8	3500
4000- 5999	44	1246	3824	200620	121	9697	4559,5	5000
6000- 7999	27	765	3059	173780	105	9592	6436,3	7000
8000- 9999	11	312	2747	93900	57	9535	8536,4	9000
10000- 19999	37	1048	1699	473888	286	9249	12807,8	15000
20000- 29999	17	482	1217	366074	221	9028	21533,8	25000
30000- 39999	10	283	934	315200	190	8836	31520,0	35000
40000- 59999	12	340	594	555160	335	8503	46263,3	50000
60000- 79999	6	170	424	396460	239	8284	66076,6	70000
80000- 99999	6	170	254	520000	314	7950	86666,6	90000
100000- 199999	2	57	197	298000	180	7770	149000,0	150000
200000- 299999	4	113	84	866800	523	7247	216700,0	250000
300000- 399999	0	0	84	0	0	7247	0,0	350000
400000- 599999	0	0	84	0	0	7247	0,0	500000
600000- 799999	0	0	84	0	0	7247	0,0	700000
800000- 999999	0	0	84	0	0	7247	0,0	900000
1000000- 1999999	0	0	84	0	0	7247	0,0	1499999
2000000- 2999999	2	57	27	4000000	2415	4832	2000000,0	2499999
3000000- 3999999	0	0	27	0	0	4832	0,0	3499999
4000000- 5999999	0	0	27	0	0	4832	0,0	4999999
6000000- 7999999	0	0	27	0	0	4832	0,0	6999999
8000000- 9999999	1	28	0	8000000	4830	2	8000000,0	8999999
10000000- 19999999	0	0	0	0	0	2	0,0	14999999
20000000- 29999999	0	0	0	0	0	2	0,0	24999999
30000000- *****	0	0	0	0	0	2	0,0	*****
TOTAL	353	10001	0	16561561	9998	2	46916,6	

ALL FACILITIES CLASS INTERVAL (GALLONS)	INCIDENTS			VOLUME			SET-4 SHEETES	
	NUMBER	FREQUENCY	I-CUM FREQUENCY	SPILLAGE	FREQUENCY	I-CUM FREQUENCY	AVERAGE SPILL	CLASS MARK
1000- 1999	219	2870	7130	272754	113	9887	1245,5	1500
2000- 2999	113	1481	5649	248882	103	9784	2202,5	2500
3000- 3999	62	813	4836	199525	82	9702	3218,1	3500
4000- 5999	107	1402	3434	484040	200	9502	4523,7	5000
6000- 7999	58	760	2674	380060	157	9345	6552,8	7000
8000- 9999	31	406	2268	264092	109	9236	8519,1	9000
10000- 19999	68	691	1377	833715	344	8892	12260,5	15000
20000- 29999	31	406	971	693564	286	8606	22373,0	25000
30000- 39999	14	183	788	452636	167	8419	32331,1	35000
40000- 59999	22	288	500	993160	410	8009	45143,6	50000
60000- 79999	6	79	421	396460	164	7845	66076,6	70000
80000- 99999	7	92	329	615000	254	7591	87857,1	90000
100000- 199999	11	144	185	1643540	678	6913	149412,7	150000
200000- 299999	6	79	106	1349800	557	6356	224966,6	250000
300000- 399999	0	0	106	0	0	6356	0,0	350000
400000- 599999	3	39	67	1445000	596	5760	481666,6	500000
600000- 799999	0	0	67	0	0	5760	0,0	700000
800000- 999999	1	13	54	960000	396	5364	960000,0	900000
1000000- 1999999	1	13	41	1008000	416	4948	1008000,0	1499999
2000000- 2999999	2	26	15	4000000	1650	3298	2000000,0	2499999
3000000- 3999999	0	0	15	0	0	3298	0,0	3499999
4000000- 5999999	0	0	15	0	0	3298	0,0	4999999
6000000- 7999999	0	0	15	0	0	3298	0,0	6999999
8000000- 9999999	1	13	2	8000000	3300	-1	8000000,0	8999999
10000000-19999999	0	0	2	0	0	-1	0,0	14999999
20000000-29999999	0	0	2	0	0	-1	0,0	249999984
30000000-*****	0	0	2	0	0	-1	0,0	*****
OVERALL	763	9998	2	24240228	10002	-1	31769,6	

ALL PIRS DATA CLASS INTERVAL (GALLONS)	INCIDENTS			VOLUME			SET#4 SHEET#6 AVERAGE SPILL	CLASS MARK
	NUMBER	FREQUENCY	1-CUM FREQUENCY	SPILLAGE	FREQUENCY	1-CUM FREQUENCY		
1000- 1999	338	2983	7017	415464	97	9903	1229,2	1500
2000- 2999	164	1447	5570	359912	84	9819	2194,6	2500
3000- 3999	86	759	4811	277324	65	9754	3224,7	3500
4000- 5999	156	1377	3434	704248	164	9590	4514,4	5000
6000- 7999	76	671	2763	499775	116	9474	6576,0	7000
8000- 9999	44	388	2375	371538	86	9388	8444,0	9000
10000- 19999	89	786	1589	1109525	258	9130	12466,6	15000
20000- 29999	44	388	1201	996564	232	8898	22649,2	25000
30000- 39999	19	168	1033	633294	147	8751	33531,3	35000
40000- 59999	31	274	759	1427214	332	8419	46039,2	50000
60000- 79999	14	124	635	913460	213	8206	65247,1	70000
80000- 99999	13	115	520	1123522	202	7944	86424,8	90000
100000- 199999	25	221	299	3577612	833	7111	143104,4	150000
200000- 299999	13	115	184	2879246	670	6441	221480,4	250000
300000- 399999	5	44	140	1754000	408	6033	350800,0	350000
400000- 599999	4	35	105	1970000	459	5574	492500,0	500000
600000- 799999	0	0	105	0	0	5574	0,0	700000
800000- 999999	3	26	79	2650000	617	4957	883333,3	900000
1000000- 1999999	4	35	44	5293910	1232	3725	1323477,0	1499999
2000000- 2999999	4	35	9	8000000	1862	1863	2000000,0	2499999
3000000- 3999999	0	0	9	0	0	1863	0,0	3499999
4000000- 5999999	0	0	9	0	0	1863	0,0	4999999
6000000- 7999999	0	0	9	0	0	1863	0,0	6999999
8000000- 9999999	1	9	0	8000000	1862	1	8000000,0	8999999
10000000-19999999	0	0	0	0	0	1	0,0	14999999
20000000-29999999	0	0	0	0	0	1	0,0	249999984
30000000-*****	0	0	0	0	0	1	0,0	*****
OVERALL	1133	10000	0	42956608	9999	1	37914,0	

TOTAL INCIDENTS BY NOTIFIER BY SOURCE SET=5 SHEET 1
SPILLER COMMERCIAL PRIVATE PTY

VESSEL	3221	475	269	EPA	OTHR GOV	USCG	UNKNOWN	TOTAL
CNSHORE TRANSPORT	606	60	75	51	181	224	116	1313
CFF SHORE TRANSPORT	264	5	8	0	4	5	9	295
CNSHORE NON-TRANSPORT	709	64	134	25	15	459	112	1662
CFFSHORE NON-TRANSPORT	1773	9	10	0	12	21	160	1985
UNKNOWN SOURCE	1649	1002	754	19	547	1327	580	5878
TOTAL	6222	1618	1250	104	1284	2898	1152	16528

	INCIDENTS		SET#5		SHEET# 2		CAPSIZING	EXPLOSION	FIRE/	SINKING/	OTHER	CASUALTY	TOTAL
	COLLISION	COLLISION	COLLISION	SUBTOTAL	GROUNDING	COLLISION							
VESS 71+72	F.0.71+72	F.0.71+72	73 ONLY	COLLISION									
TANKSHIP	5	0	13	26	49	0	3	3	7	88			
TANK BARGE	35	40	32	107	66	4	2	13	13	205			
TOW/TUG BOAT	2	2	3	7	9	2	1	40	1	60			
DRY CARGO BARGE	1	0	1	2	1	2	2	8	1	16			
DRY CARGO VESSEL	0	3	2	5	10	1	9	4	1	30			
ALL OTHER VESSELS	10	6	18	34	37	12	19	150	4	256			
TOTAL	53	59	69	181	172	21	36	216	27	655			

[illegible]

COLLISION VESSELS	AUG. SPILL		SET#5		SHEETS# 4		FIRE/ EXPLOSION	SINKING/ FOUNDERING	OTHER CASUALTY	TOTAL
	COLLISION VESSELS	COLLISION VESSELS	COLLISION VESSELS	COLLISION VESSELS	SUBTOTAL COLLISION	GROUNDING CAPSIZING				
TANKSHIP	212529	70720	225721	179734	48588	0	50	104	265	80948
TANK BARGE	25957	26568	20052	24410	23929	506331	46	168767	534	43791
TOW/TUG BOAT	0	75	176172	105733	1479	1	0	409	80	12507
DRY CARGO BARGE	4000	0	0	4000	0	265	199001	5575	60000	59210
DRY CARGO VESSEL	0	263	900	581	666	0	91	3000	5	472
ALL OTHER VESSELS	2429	30	20831	13569	1959	1007	732	2734	96	4221
TOTAL	38424	28046	61008	44302	24073	145208	17603	137500	2940	2956